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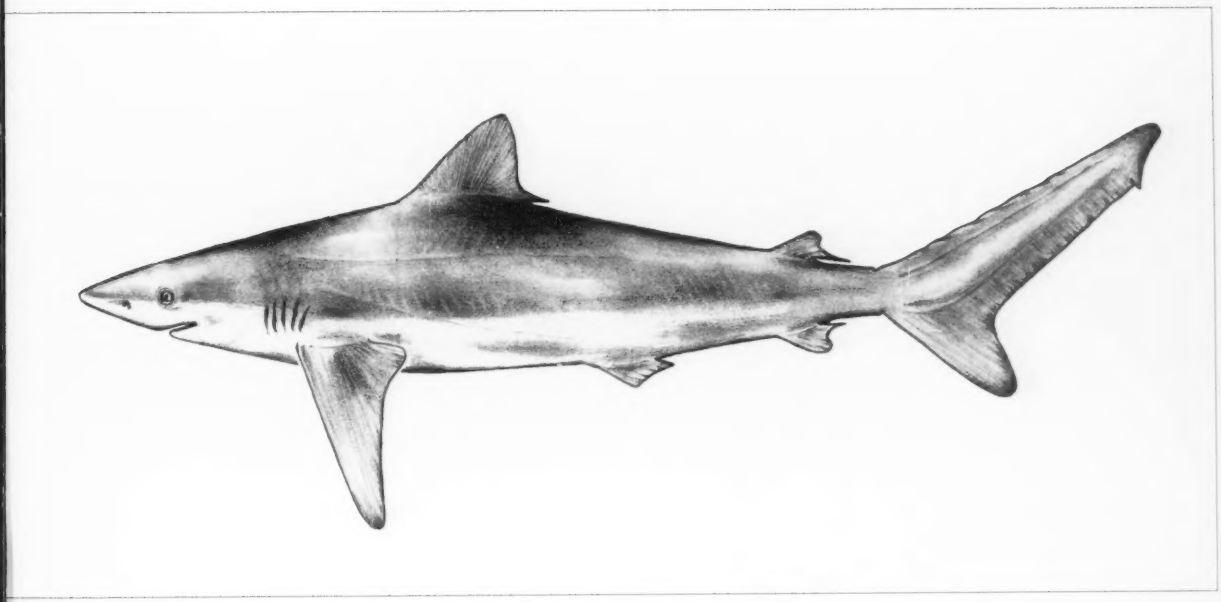

Night Shark

Marine Fisheries REVIEW

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On the cover:
The night shark,
Carcharhinus signatus.
Illustration by Mark Grace
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Articles *70(1), 2008*

The Status of the United States Population of Night Shark, *Carcharhinus signatus* — *John K. Carlson, Enric Cortes, Julie A. Neer, Camilla T. McCandless,* and *Lawrence R. Beerkircher* **1**

Transboundary Movement of Atlantic Istiophorid Billfishes Among International and U.S. Domestic Management Areas Inferred from Mark-Recapture Studies — *E. S. Orbesen, J. P. Hoolihan, J. E. Serafy, D. Snodgrass, E. M. Peel,* and *E. D. Prince* **14**

Stanford University's John Otterbein Snyder: Student, Collaborator, and Colleague of David Starr Jordan and Charles Henry Gilbert — *Martin R. Brittan* and *Mark R. Jennings* **24**

Fisheries History

My Days on the *Albatross* — *Seaton Schroeder* **30**

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The Status of the United States Population of Night Shark, *Carcharhinus signatus*

JOHN K. CARLSON, ENRIC CORTES, JULIE A. NEER,
CAMILLA T. MCCANDLESS, and LAWRENCE R. BEERKIRCHER

Introduction

The first fishery management plan for shark populations in waters of the United States (U.S.) Atlantic Ocean and Gulf of Mexico was developed in 1993 (NMFS, 1993). Because species-specific catch and life history information was limited, sharks were grouped and managed under three categories (large coastal, small coastal, and pelagic) based on known life history, habitat, market, and fishery characteristics (NMFS, 1993). The Fishery Management Plan of the Atlantic tunas, swordfish, and sharks (NMFS, 1999) added a fourth category and prohibited the retention of 19 species of sharks (Prohibited Species management category) based on a precautionary approach for species with little or no biological information that were thought to be highly susceptible to overexploitation.

The U.S. Endangered Species Act (ESA) is designed to provide for the conservation of endangered and threatened species and to take appropriate steps to recover a species. When a species is listed as endangered under the ESA, it is afforded all protections of the ESA, including the development and implementation of recovery plans, requirements that Federal agencies use their authority to conserve the species, and prohibitions against certain practices, such as taking individuals of the species.

Generally, species are considered for listing under the ESA if they meet the definition of an endangered or threatened species and that status is the result of one or any combination of the following factors: 1) present or threatened destruction, modification, or curtailment of its habitat or range; 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; or 5) other natural or manmade factors affecting its continued existence. In establishing its species of concern list, NMFS determined that factors related to the demography and vulnerability of a species will be evaluated to determine whether the species represents a species of concern (71 CFR 55431). NMFS developed the following factors to be considered in evaluating vulnerability: 1) abundance and productivity, or magnitude of decline (in terms of recent and historical rates); 2) natural rarity and endemism; 3) distribution; and 4) life history characteristics.

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ABSTRACT—Night sharks, Carcharhinus signatus, *are an oceanic species generally occurring in outer continental shelf waters in the western North Atlantic Ocean including the Caribbean Sea and Gulf of Mexico. Although not targeted, night sharks make up a segment of the shark bycatch in the pelagic longline fishery. Historically, night sharks comprised a significant proportion of the artisanal Cuban shark fishery but today they are rarely caught. Although information from some fisheries has shown a decline in catches of night sharks, it is unclear whether this decline is due to changes in fishing tactics, market, or species identification. Despite the uncertainty in the decline, the night shark is currently listed as a species of concern due to alleged declines in abundance resulting from fishing effort, i.e. overutilization.*

To assess their relevance to the species of concern list, we collated available information on the night shark to provide an analysis of its status. Night shark landings were likely both over- and under-reported and thus probably did not reflect all commercial and recreational catches, and overall they have limited relevance to the current status of the species. Average size information has not changed considerably since the 1980's based on information from the pelagic longline fishery when corrected for gear bias. Analysis of biological information indicates night sharks have intrinsic rates of increase (r) about 10% yr^{-1} and have moderate rebound potential and an intermediate generation time compared to other sharks. An analysis of trends in relative abundance from four data sources gave conflicting results, with one series in decline, two series increasing, and one series relatively flat. Based on the analysis of all currently available information, we believe the night shark does not qualify as a species of concern but should be retained on the prohibited species list as a precautionary approach to management until a more comprehensive stock assessment can be conducted.

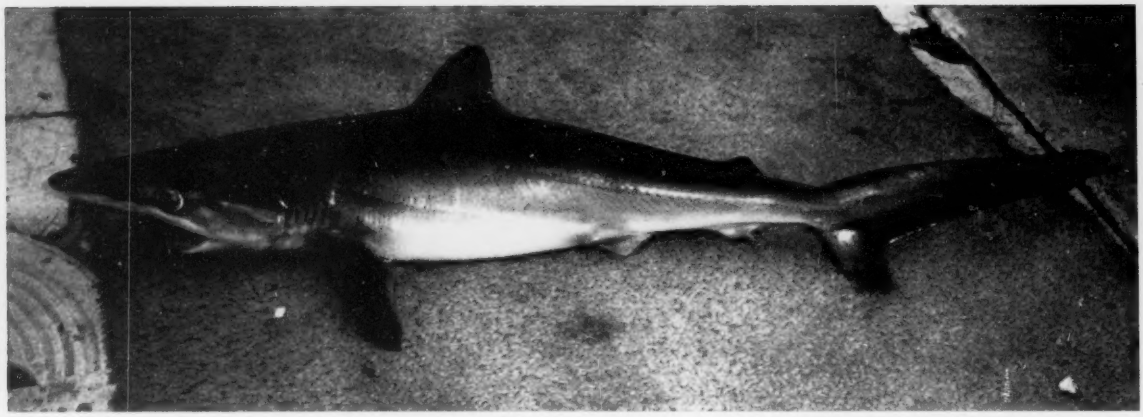

Figure 1.—A night shark captured in the swordfish pelagic longline fishery.

The night shark, *Carcharhinus signatus* (Fig. 1) is a medium-sized shark (maximum reported size 276 cm total length) characterized by a gray blue body with a long snout, an interdorsal ridge, and large green eyes. Night sharks are similar in morphology to silky, *C. falciformis*, and dusky, *C. obscurus*, sharks and are usually distinguished from these species by the placement of the first dorsal fin and the length of the second dorsal fin free rear tip (Castro, 1983). Night sharks have broad upper teeth with prominent basal serrations with distinct notches along margin and oblique cusps (Bigelow and Schroeder, 1948; Garrick, 1985). They are an oceanic species generally occurring in outer continental shelf waters in the northwest Atlantic Ocean from Delaware south to the Florida Straits including the Caribbean Sea and Gulf of Mexico (Bigelow and Schroeder, 1948; Compagno, 1984). Night sharks are generally found from 50 to 600 m in depth (Compagno, 1984) but specimens have been collected from 26 to 2,000 m (Bigelow and Schroeder, 1948; Branstetter, 1981). The World Conservation Union (IUCN) currently lists night shark globally as vulnerable based on population declines throughout its western Atlantic Ocean range due to target and bycatch exploitation by fisheries (Santana el al., 2006).

In the northwest Atlantic Ocean, night sharks historically comprised a significant proportion of the artisanal Cuban shark fishery, making up to 60–75% of the catch from 1937 to 1941 (Martinez, 1947). Beginning in the 1970's with the development of the swordfish fishery, anecdotal evidence suggested a substantial decline in the abundance of this species. Guitart-Manday (1975) documented a decline in the mean weight per unit of effort for night sharks from 53.4 kg in 1971 to 21.1 kg in 1973. Night sharks comprised 26.1% of the shark catch in a segment of the pelagic longline fishery from 1981 to 1983 (Berkeley and Campos, 1988), but this declined to 0.3% and 3.3% of the shark catch in 1993 and 1994, respectively, based on observer data (Beerkircher[1]). Further, photographic evidence from marlin tournaments in south Florida showed that large night sharks were caught daily in the 1970's but are rarely captured today (Castro et al., 1999).

The night shark is currently listed as a Prohibited Species (NMFS, 1999) but was originally petitioned and added to the Candidate Species List[2] under the Endangered Species Act in 1997. NMFS identified the night shark as an ESA candidate species due to alleged declines in abundance resulting from fishing effort (i.e. overutilization). On 15 April 2004, NMFS announced the establishment of a species of concern list, a description of the factors that it will consider when identifying species of concern, and revision of the ESA Candidate Species List.[3] NMFS transferred 25 candidate species, including night sharks, to the species of concern list.

Although information from some fisheries has shown a decline in catches of night sharks, it is unclear whether this decline is due to changes in fishing tactics, markets, species identification or real population declines. Furthermore, no studies have estimated the demography and productivity of the night shark, which is necessary in its evaluation as a species of concern. Our goal was to collate all available information on the night shark to provide a preliminary analysis of its status and assess its relevance to the list of species of concern.

Materials and Methods

Life History

Life history information is currently not available for night shark populations in the northwest Atlantic Ocean. To construct demographic models, we summarized all available life history information from the literature and conducted analyses from those data where appropriate.

[1]Beerkircher, L. Unpubl. data on file at NMFS, Southeast Fish. Sci. Cent., 75 Virginia Beach Dr., Miami, FL 33149.

[2]Online at http://www.nmfs.noaa.gov/pr/species/concern.

[3]NMFS, Revision of Candidate Species List Under the Endangered Species Act, 2004, Federal Register paper 69 FR 19975)

Natural Mortality, Productivity, and Elasticity Estimation

The instantaneous rate of natural mortality (M) was estimated through multiple indirect life history methods described extensively elsewhere (see Cortés, 2002, and references therein). The maximum age-specific estimate from those values produced that most likely represented the life history for sharks was selected as a proxy to account for a density-dependent compensatory response that would be expected to occur at low population density, and was then used in a life table/matrix population model approach. Two methods for calculating population growth rates were used: life tables and Leslie matrix population models. These allow calculation of net reproductive rate (R_0), generation length (T) (Caughley, 1966), finite population growth rate ($\lambda = e^r$), and elasticities (proportional sensitivities; Caswell, 2001) for age-0 survival or fertility, juvenile survival, and adult survival. Other quantities of interest, such as the steepness of the stock-recruit curve and the maximum lifetime reproductive rate at low population densities, were also calculated.

Productivity was also calculated through a modified demographic technique that incorporates concepts of density dependence (Smith et al., 1998). In this method, rebound potentials or productivity (r_z) is calculated at the population level producing MSY (maximum sustainable yield), which is assumed to occur at Z = 1.5M (Z = total instantaneous mortality rate).

To incorporate uncertainty in our knowledge of vital rates for this species, we conducted a Monte Carlo simulation, a projection process which involved randomly selecting a set of life-history traits (derived from this study and published literature) from the probability density functions describing each individual trait, and calculating λ, T, and age-0, juvenile, and adult survival elasticities in the life table/matrix population model approach and productivity (r_z) in the modified demographic technique. This process was repeated 10,000 times, yielding frequency distributions, means, and confidence intervals (calculated as the 2.5th and 97.5th percentiles) for parameter estimates. All simulations were run with MS Excel spreadsheet software equipped with risk analysis and matrix algebra software and MS Visual Basic.[4]

Catch Analysis

U.S. commercial landings of night sharks were compiled based on NMFS northeast regional and southeast regional general canvass data which is based on the quantity of seafood products that are sold to established (licensed) wholesale and retail seafood dealers, and the Southeast Fisheries Science Center quota monitoring data based on southeastern region permitted shark dealer reports. The larger of the two reported landings of night shark (southeast regional general canvass landings data vs. the SEFSC quota monitoring data) was taken as the actual landed volume for that species in the southeast. The reported northeast regional general canvass landings for night sharks were then added to obtain the total commercial landings. Northeast regional and southeast regional general canvass landings data are reported in whole weight (ww) and were further expressed as dressed weight (dw) by using a conversion factor of 1.96 (Cortés and Neer[5]). Landings in the SEFSC quota monitoring system are reported in dressed weight.

Recreational fishing estimates (in numbers of fish) were obtained from three data collection programs: the Marine Recreational Fishery Statistics Survey (MRFSS), the NMFS Headboat Survey (HBOAT) operated by the SEFSC Beaufort Laboratory, and the Texas Parks and Wildlife Department Recreational Fishing Survey (TPWD). Dead discards of night sharks in fisheries targeting tuna and tuna-like species were compiled from mandatory logbooks on longline and other vessels (Large Pelagic Logbook) and observer reports from these fisheries (SEFSC Pelagic Longline Observer Program) as reported in various publications (details are given in Cortés and Neer[5]). The majority of these vessels (90%) use longline gear (Cramer, 2002). Discards are typically recorded in numbers and whole weight and were further expressed as dressed weight as above. Dead discard estimates were available starting in 1987.

Size Information

Length information for night sharks was obtained from the SEFSC Pelagic Longline Observer Program. Regression analysis was used to examine trends in size with time (year).

Catch Rate Analysis

Databases were examined for the presence of night sharks, and nominal catch rates by year were calculated. Where appropriate, catch rates were standardized using a form of generalized linear model analysis. In most cases, a two-part generalized linear model analysis originally proposed by Lo et al. (1992) was utilized. The method models the proportion of sets with positive catches (where at least one shark was caught) assuming a binomial distribution with a logit link function, whereas the second step models the catch rates or catches of sets with positive catches assuming a lognormal or Poisson distribution, respectively. Time, area, and fishery operational factors were considered as potential influences on catch rates, if available.

For each generalized linear model, a stepwise approach to quantify and eliminate factors was employed (Ortiz and Arocha, 2004). First, a null model was run with no factors to reflect the distribution of the nominal data. Each potential factor was then added to the null model one at a time. Any factor that caused a reduction in deviance per degree of freedom was added to the base model if the factor was significant based on a Chi-Square test ($p<0.05$) and if the reduction in deviance per degree of freedom was at least 1%. This process was repeated, adding factors individu-

[4]Mention of trade names or commercial firms does not imply an endorsement by the National. Marine Fisheries Service, NOAA.

[5]Cortés, E., and J. A. Neer 2005. Updated catches of Atlantic sharks. Southeast Data, Assessment, and Review Document LCS05/06-DW-16. U.S. Dep. Commer., NOAA, NMFS, Southeast Fish. Sci. Cent., Panama City, FL, 58 p.

ally from the most to the least influential until no factor met the criteria. Because of the low sample size and its influence on the ability of the model to converge, we considered only first-order interactions. Regardless of its significance, year was kept as a factor in the final model. Parameterization of each model was accomplished using the SAS statistical computer software.[6]

After selecting the set of fixed factors and interactions for each error distribution, all interactions that included the factor year were treated as random interactions (Ortiz and Arocha, 2004). This process converted the basic models from generalized linear models into generalized linear mixed models. The final model determination was evaluated using the Akaike Information Criterion (AIC) and Schwarz's Bayesian Criterion (BIC; Littell et al., 1996). Models with smaller AIC and BIC values are preferred to those with larger values. These models were fit using a SAS macro, GLIMMIX (Wolfinger and O'Connell, 1993), and the MIXED procedure in the SAS statistical computer software. Relative indices of abundance were calculated as the product of the year effect least squares means from the two independent models. The standard error of the combined index was estimated with the delta method (Appendix 1 in Lo et al., 1992). Trends in abundance were further analyzed with regression techniques.

Results

Life History and Demography

Age and Growth

Santana and Lessa (2004) aged 317 night sharks collected off the northeast coast of Brazil between 1995 and 1999. The von Bertalanffy growth model fit to those age data estimated growth parameters as $L_\infty = 265$ cm total length (TL), $K = 0.11$ yr^{-1} and $t_0 = -2.69$ yr for females, and $L_\infty = 256$ cm TL, $K = 0.12$ yr^{-1} and $t_0 = -2.54$ yr for males (Table 1). The oldest aged specimens were 17 yr. The age at which 95% of L_∞ (i.e. theoretical longevity; Fabens, 1965) is reached was 30.4 and 27.9 yr for females and males, respectively.

Reproduction

Based on 744 specimens from the southwestern equatorial Atlantic Ocean, Hazin et al. (2000) estimated the sizes of maturity were 200–205 cm TL and 185–190 cm TL for female and male night sharks, respectively. Age at maturity was estimated at 8 yr for males and 10 yr for females (Hazin et al., 2000). Copulation appears to take place during the month of February in the southwest Atlantic Ocean, but its timing is unknown for areas above 10°N Latitude. Females give birth to 4–15 pups (mean litter size 11.1) of 50–60 cm TL (Hazin et al., 2000; Carlson[7]).

Productivity, Natural Mortality, and Elasticity

Instantaneous rates of natural mortality (M) estimated through a variety of methods ranged from 0.92 to 0.65 yr^{-1} when expressed as annual rates of survivorship. Pup survival at low population density was 0.84 yr^{-1}. Productivity (rebound potential) was 0.021 yr^{-1} when the population level that produces MSY is assumed to occur at Z=1.5M. With the life table/Leslie matrix approach, estimated population growth rate (λ) was 1.101 yr^{-1} (1.075–1.124 95% confidence intervals).

Mean (and 95% confidence intervals) generation time was 13.8 yr (12.6–15.3), net reproductive rate was 3.8 (2.7–5.2), maximum lifetime reproductive rate was 3.24 (2.3–4.4), and steepness was 0.44 (0.36–0.52). Population growth rate elasticities were 6.9% (6.3–7.5%) for fertility, 65.7% (60.8–70.6%) for juvenile survival, and 27.3% (22.3–32.5) for adult survival.

Exploitation

Commercial Fishery

While night sharks are not targeted, the high value and demand for shark fins, along with species identification issues, usually result in some night sharks being retained despite the species being prohibited since 1999. Since 1995, commercial landings have averaged 1,414 kg dressed weight (dw), with the highest reported landings (3,605 kg dw) occurring in 1999 and the lowest (10 kg dw) in 2002 (Table 2). No commercial landings have been reported since 2003.

Night sharks are primarily caught in pelagic longline fisheries as bycatch. According to data from the pelagic logbook program, an average of 441 night sharks were discarded dead per year during 1987–2002. Peak numbers of discards occurred in 2000, when night sharks were first prohibited, but since 2002 no night sharks have been reported discarded dead. Data from the pelagic longline observer program indicate that of the 1,655 night sharks observed caught since 1994, 12.5% were kept, 64.2% were discarded dead, and 22.5% were released alive. Beerkircher et al. (2002) stated that night sharks comprised 12.4% of the total shark bycatch reported by fisheries observers aboard U.S. pelagic longline vessels in 1992–2000. In contrast, Berkeley and Campos (1988) reported night sharks were 26.1% of the total shark catch in a study on pelagic shark bycatch from the swordfish fishery off southeast Florida during 1981–1983.

Recreational Fishery

Recreational catches of night sharks have been variable (Table 2). In 1982, 2,300 sharks were reported caught but no night sharks were reported again until 1986 (12). Since 1987, annual recreational catches of night sharks have ranged from 460 to 0. No night sharks have been reported caught since 2000. Additional data from the large pelagic survey, which collects catch rate information on rod and reel and handline fisheries off the coast of the eastern United States from Virginia through Massachusetts, indicate only 8 night sharks were recorded during 1986–2005 (Brown[8]).

[6]PROC GENMOD; Version 8.02 of the SAS System for Windows 2000. SAS Institute Inc.

[7]Carlson, J. Unpubl. data on file at NMFS, Southeast Fish. Sci. Cent., 3500 Delwood Beach Road, Panama City, FL 32408

[8]Brown, C. October, 2006. NMFS, Southeast Fish. Sci. Cent., 75 Virginia Beach Dr., Miami, FL 33149. Personal commun.

Table 1.—A summary of life history parameters for night sharks. All length values are in cm total length. Fecundity is the mean number of pups and the number in parentheses represents the ranges reported.

Parameter	Male	Female	Combined	Area of study	Source
Theoretical maximum length (L_∞)	256.5	265.4	270.0	Southwest Atlantic Ocean	Santana and Lessa, 2004
Growth coefficient (K, yr^{-1})	0.124	0.114	0.112	Southwest Atlantic Ocean	Santana and Lessa, 2004
Time at zero length (t_0, yr)	−2.538	−2.695	−2.705	Southwest Atlantic Ocean	Santana and Lessa, 2004
Maximum observed age (yr)	17	17		Southwest Atlantic Ocean	Santana and Lessa, 2004
Theoretical maximum age (yr)	27.9	30.4		Southwest Atlantic Ocean	Santana and Lessa, 2004
Age at maturity (yr)	8	10		Southwest Atlantic Ocean	Hazin et al., 2000
Length at maturity	185–190	200–205		Southwest Atlantic Ocean	Hazin et al., 2000
Fecundity (pups)		11.1 (4–15)		Southwest Atlantic Ocean	Hazin et al., 2000
Size at birth			50–60	Northwest Atlantic Ocean	This study, Compagno, 1984

Average Size

Fork lengths from the pelagic longline observer program from 1994 to 2005 show a generally flat trend (Fig. 2). No significant relationship was found in length over time ($p = 0.65$, $r^2 = 0.0002$). In a pilot study of the swordfish longline fishery off Florida's East Coast conducted during 1981–83, Berkeley and Campos (1988) reported the average size of night sharks caught was 150.4 cm FL. Average size was 96.5 cm FL in 1994 and 101.7 cm FL in 2005. These observations indicate a decrease in average size of about 40 cm since the early 1980's. However, samples from Berkeley and Campos (1988) may have been obtained from night sharks caught using wire leaders as opposed to monofilament leaders utilized in the pelagic longline fishery. The effect of various leader types on shark catchability is a subject of further investigation, but recent fishery-independent pelagic surveys using wire leaders reported an average size for night sharks ($n = 26$) of 140 cm FL (Ingram[9]).

Table 2.—Estimates of total catches and dead discards for night sharks from U.S. Atlantic waters, 1981 to 2005.

	Landings		Bycatch		
	Commercial[1]	Recreational[2]	Pelagic longline discards[3]		
Year	Dressed wt (kg)	No.	No.	Whole wt (t)	Dressed wt (kg)
1981		0			
1982		2,300			
1983		0			
1984		0			
1985		0			
1986		12			
1987		10	0	0	0
1988		460	0	0	0
1989		57	0	0	0
1990		0	0	0	0
1991		29	0	0	0
1992		54	0	0	0
1993		58	22	0.16	82
1994		42	380	3.26	1,667
1995	2,882	245	128	1.26	644
1996	3,469	379	0	0	0
1997	15	90	0	0	0
1998	1,520	133	921	20.25	10,353
1999	3,605	50	1,586	20.62	1,054
2000	1,247	24	4,100	88.57	45,283
2001	2,679	0	1,233	24.96	12,761
2002	10	0	0	0	0
2003	121	0	0	0	0
2004	0	0	0	0	0
2005	0	0	0	0	0

[1] Data for 1995–2005 are the sum of the Southeast Quota Monitoring System/Southeast General Canvass Program and the dealer weighout estimates.
[2] Except for 1982 and 1988, all recreational catches are from the NMFS Headboat survey.
[3] Pelagic longline discards are estimated from commercial logbook data and observer reports.

Catch Rates

We examined 11 potential historic and current data sources (Table 3) for the presence of night sharks. Of the data sources examined, we determined that only four data sources contained adequate information for the calculation of standardized catch rate series, as follows.

NEFSC Longline Surveys

The NMFS, and its predecessor agencies, the Bureau of Commercial Fisheries (BCF) and the Bureau of Sport Fisheries and Wildlife (BSFW), have conducted periodic longline surveys for swordfish, tuna, and sharks off the east coast of the United States since the early 1950's. The initiation of shark surveys in 1961 at the BSFW-Sandy Hook Marine Laboratory (SHML) responded to concerns about shark attacks off the coast of New Jersey and resort owner demands for legislation that would require sport and commercial fishermen to fish further offshore. While surveys predominantly relied on longline gear, early sampling also used chain bottom gear, gillnets, and sport fishing gear. In subsequent years, monitoring of sport fishing tournaments during summer months complemented dedicated surveys on research vessels and opportunistic trips aboard commercial and sport fishing vessels. Early experimentation with different tag types ultimately lead to the establishment of the ongoing Cooperative Shark Tagging

[9]Ingram, W. August, 2007. NMFS, Southeast Fish. Sci. Cent., P.O. Drawer 1207, Pascagoula, MS 39568. Personal commun.

Program currently based at the NMFS Narragansett Laboratory (NARR). After the initial coastal surveys were conducted between 1961 and 1965, there was a gradual transition from coastal work to offshore effort along the edge of the continental shelf and associated Gulf Stream waters. The shark research program moved from SHML to NARR in the early 1970's.

A total of 1,916 longline set records were recorded from historic cruise files. These included: 340 sets by the BSFW-SHML between 1961 and 1970; 1,488 sets on NMFS-NARR surveys between 1975 and 1996; 44 sets from cruises sponsored by other institutions where NARR staff participated; and 44 sets from opportunistic deployments of scientists aboard volunteer commercial vessels. Only sets that were conducted in depths greater than 100 m, surface water temperatures less than 30° Celsius, at latitudes of 39° or less, and with pelagic sharks as the target species were used in these analyses. Of the 1,916 total sets, 224 sets had sufficient data and were used to model catch rates of night sharks. Night sharks were represented in 10.7% of the sets. Factors considered in the generalized linear models of night shark catch rates were year, area (long. <34.5°W, long. 34.5–37°W, long. 37.1–39°W), season, temperature, and leader type (wire or monofilament).

The final generalized linear mixed model for NEFSC night shark catch rates included year as a single fixed factor in the binomial model of the proportion of positive sets and the factors year and area in the Poisson model of positive catch sets (Table 4). An offset of the natural log of the number of hooks was used in the Poisson model.

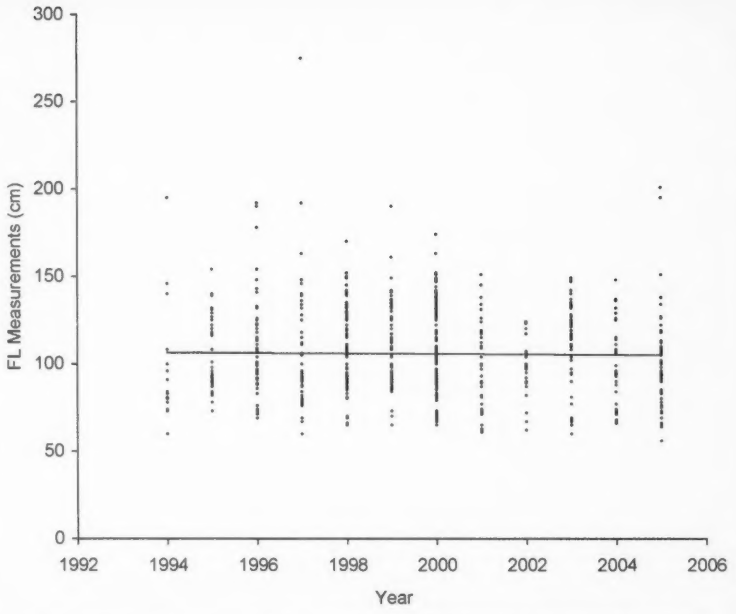

Figure 2.—Lengths of night sharks measured in the Pelagic Longline Observer Program, 1994–2006. The line indicates a linear regression fit to the data

There were no longline sets conducted in 1967, 1970, 1972, 1974, 1975, 1982, 1987, 1990, 1993, or 1995 that met the criteria for inclusion in these analyses. From the longline sets that were included, there were no catches of night sharks during 1968, 1969, 1976, 1977, 1978, 1983, 1988, 1989, 1992, 1994, or 1996. There is an overall decreasing trend in relative abundance for the NEFSC time series during the years covered from 1966 to 1996 (Figure 2). This trend is largely driven by the high relative abundance at the beginning of the time series (1966), which is the result of a single high catch set in a year with low effort (three sets total in 1966).

SEFSC Pelagic Data Program Longline Logbook

The Pelagic Longline Logbook (PLL) Data Program records the fishing and non fishing activity of fishermen who are required to report their fishing activity via logbooks submitted for each trip. The

Table 3.—A summary of data sets examined for the presence of night sharks. Years refers to the time period covered by the data set, beginning with the oldest. A year followed by a dash denotes an ongoing survey or program. Type refers to whether the index is from a commercial or recreational source, or is fishery-independent from a scientific survey. Area indicates the area covered by the survey or fishery. An asterisk indicates the series was utilized in a generalized linear model analysis.

Data Set	Years	Type	Area
SEFSC Mississippi Laboratories Historical Survey	1954–1957	Scientific Survey	Gulf of Mexico
NEFSC Laboratory Longline Surveys*	1961–1996	Scientific Survey	NW Atlantic Ocean
Japanese Commercial Logbook Program	1971–2006	Commercial	NW Atlantic Ocean
R/V *Geronimo* Longline Survey	1977–1994	Scientific Survey	NW Atlantic Ocean
Japanese Longline Observer Program	1978–1988	Commercial	NW Atlantic Ocean, Gulf of Mexico
Large Pelagic Survey	1986–	Recreational	Mid-NW Atlantic Ocean
Pelagic Longline Logbook Program*	1986–	Commercial	NW Atlantic Ocean, Gulf of Mexico
Pelagic Longline Observer Program*	1992–	Commercial	NW Atlantic Ocean, Gulf of Mexico, Caribbean Sea
Berkeley and Campos (1988)	1981–1993	Commercial	East Florida, Atlantic Ocean
Shark Bottom Longline Observer Program*	1994–	Commercial	NW Atlantic Ocean, Gulf of Mexico
Mississippi Laboratories Pelagic Longline Survey	2004–2006	Scientific Survey	NW Atlantic Ocean, Gulf of Mexico

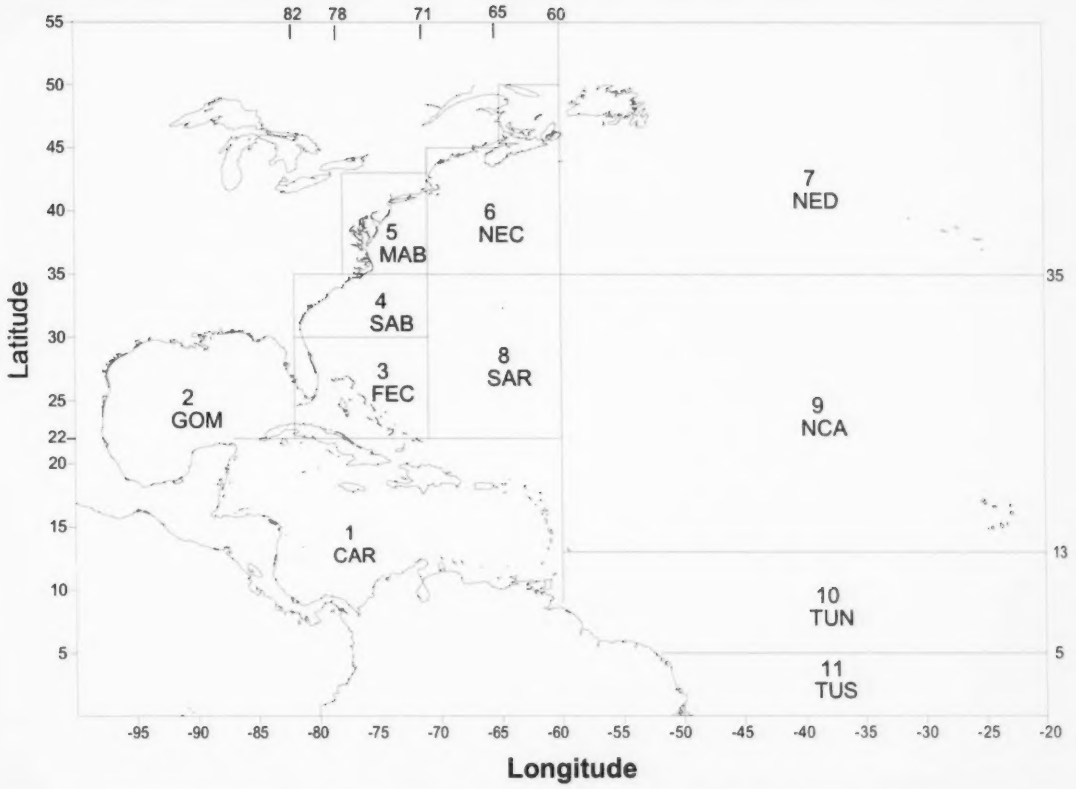

Figure 3.—Map of the western North Atlantic Ocean. Areas are as follows: 1) Caribbean Sea (CAR), 2) Gulf of Mexico (GOM), 3) Florida East coast (FEC), 4) South Atlantic Bight (SAB), 5) Mid-Atlantic Bight (MAB), 6) New England coastal (NEC), 7) Northeast distant waters (NED or Grand Banks), 8) Sargasso Sea (SAR), 9) North Central Atlantic (NCA), 10) Tuna North (TUN), and 11) Tuna South (TUS).

PLL was initiated in 1986 for the pelagic longline fishery in the U.S. northwest Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. Because this fishery uses gear that is set for a relatively long period (6–10 h), catch and effort data are collected for each set. Fishermen are required to report the number of each species caught, the number of animals retained or discarded alive or discarded dead, the location of the set by statistical grid, the types and size of gear, and the duration of the set.

The longline fishing grounds for the U.S. fleets extend from the Grand Banks in the North Atlantic to lat. 5–10°S, off the South American coast, including the Caribbean Sea and the Gulf of Mexico. Eleven geographical areas of longline fishing are defined for classification. These include: the Caribbean Sea, Gulf of Mexico, Florida East Coast, South Atlantic Bight, Mid Atlantic Bight, New England coastal, Northeast distant waters, Sargasso Sea, North Central Atlantic, Tuna North, and Tuna South (Fig. 3).

Table 4.—Factors retained in the final models of proportion of positive sets (binomial) and positive catch (lognormal or Poisson) of night sharks for the generalized linear models with associated Akaike Information Criterion (AIC).

Data Set	Model	Factors	AIC
NEFSC Laboratory Longline Surveys	Binomial	Year	971.0
	Poisson	Year+Area	53.5
Pelagic Longline Logbook Program[1]	Binomial	Area+Swordfish Quartile+Year Year*Area Year*Quarter	30.4
	Lognormal	Year+Area+Tuna Quartile Year*Area Year*Quarter	28.2
Pelagic Longline Observer Program[1]	Binomial	Area+Year+Swordfish Quartile+Quarter Year*Quarter Year*Area Tuna Quartile*Area	25.2
	Lognormal	Area+Year+Quarter+Tuna Quartile+Lightstick Year*Quarter Year*Area	26.2
Shark Bottom Longline Observer Program	Binomial	Year	5444.1
	Lognormal	Year+Depth	27.2

[1] From Cortés et al. (2007).

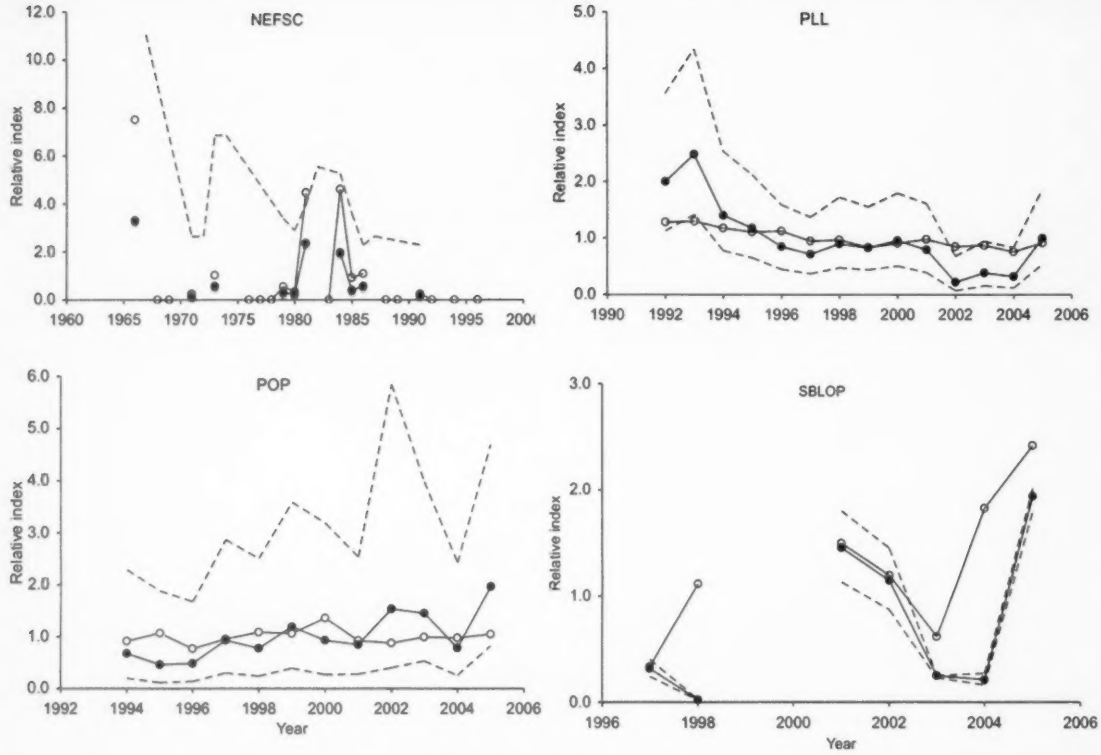

Figure 4.—Standardized relative index of abundance (solid circles) for night sharks from scientific surveys from the Northeast Fisheries Science Center (NEFSC), Pelagic Longline Logbook Program (PLL), Pelagic Longline Observer Program (POP), and the Shark Bottom Longline Observer Program (SBLOP) based on the final model. Nominal data (circles) are plotted for comparison. Confidence limits (95%) for the standardized index are dotted lines.

Data from the U.S. pelagic longline logbooks are available for 1986–2005. However, night sharks were not included in the logbooks until 1992. Night sharks made up 1.4% of the total recorded sets (2,567) since 1992. In a previous study, Cortés et al. (2007) standardized catch rates for night sharks based on methodology outlined in Brooks et al.[10] The effect of the following factors was considered in the generalized linear model: year, area, yearly quarter, fishing gear (bottom or pelagic longline), light sticks (1 or 0, depending on whether light sticks were used or not), and experiment (Y or N, depending on whether the observation was part of experimental fishing in the Northeast Distant Zone).

A proxy for target species was defined based on the proportion of swordfish or tuna catch to total catch per trip and was grouped into categories, corresponding to the quartiles 0–25%, 26–50%, 51–75% and 76–100% of these proportions (i.e. quartile for nominal tuna catch rate (per 1,000 hooks) and quartile for nominal swordfish catch rate (per 1,000 hooks)). This target variable was assumed to control for effects on night shark catch rates associated with changes of fishing operations when the fleets switch among targeted species. Further details of the results of the analysis are reported in Cortés et al. (2007).

The relative standardized index of abundance from that study initially decreased from 1992 to 1996 (Fig. 4). After 1996, the abundance index was relatively stable, with a decline in 2002 followed by an increase again in 2005 to levels prior to 2002. Overall, the logbook index showed a declining trend, largely driven by a steep decline from 1992 to 1993.

SEFSC Pelagic Data Program Longline Observer Program

The Pelagic Longline Observer Program at the NMFS SEFSC began in May of 1992. POP monitors the U.S. pelagic longline fleet ranging from the Grand Banks to Brazil and in the Gulf of Mexico. POP currently targets 8% coverage of the vessels based on the fishing effort of the fleet. Observers record fish species, length, sex, location, and other environmental information. The

[10]Brooks, E. N., M. Ortiz, L. K. Beerkircher, P. Apostolaki, and G. Scott 2004. Standardized catch rates for blue shark and shortfin mako shark from the U.S. pelagic logbook and U.S. pelagic observer program, and U.S. weightout landings. ICCAT working doc.: SCRS/2004/111, 18 p.

information collected is used to evaluate the harvest and status of the pelagic fish stocks and is important in assessing the effectiveness of management measures to control harvest levels.

Although the observer program has been in place since 1992, night sharks were not reported caught until 1994 (only 2 night sharks reported in 1993 and 1 in 1992). Night sharks were captured in 13.9% of the total observed sets since 1994. Cortés et al. (2007) also developed catch rates for night sharks based on this data source and methods similar to those described previously. In contrast to the pelagic logbook data, the relative abundance index based on observer data increased from beginning to end of the time series (Fig. 4). Relative abundance was 0.67 (lower 95% confidence limits (LCL)= 0.19, upper 95% confidence limits=2.29) sharks per 10,000 hooks in 1994 and 1.96 (LCL=0.82, UCL=4.69) sharks per 10,000 hooks in 2005.

SEFSC Shark Observer Program Bottom Longline

The shark bottom longline fishery is active in the Atlantic Ocean from about the Mid Atlantic Bight to south Florida and throughout the Gulf of Mexico. The bottom longline gear targets large coastal sharks, but small coastal sharks, pelagic sharks, and dogfish species are also caught. Observer coverage from 1994 through the 1st trimester season of 2005 was coordinated by the Commercial Shark Fishery Observer Program (CSFOP), Florida Museum of Natural History, University of Florida, Gainesville, Fla. (Burgess and Morgan[11]). Starting with the 2nd trimester season of 2005, responsibility for the fishery observer program was transferred to NMFS Southeast Fisheries Science Center's Panama City Laboratory.

Although data from the bottom longline observer program are available since 1994, night sharks were not reported caught until 1997. Since 1997, night sharks were reported on 2.2% of all observed hauls. Because most sets in this fishery were made with bottom longline gear that targeted coastal sharks, we believe many fishing trips that targeted coastal sharks had a low probability to capture night sharks. In the absence of detailed and reliable data regarding specific pelagic fishing location, bait choice, and other factors, we used an association statistic to attempt to identify trips with a higher probability of catching night sharks. The association statistic was developed using the species composition of the catch as described by Cass-Calay and Bahnick[12] and applied to goliath grouper, *Epinephelus itajara* (Cass-Calay and Schmidt[13]) and smalltooth sawfish, *Pristis pectinata* (Carlson et al., 2007):

$$\text{Association statistic} = \frac{\left(\frac{\text{Trips with Night Shark+Species}}{\text{Trips with Night Shark}} \times\right)}{\left(\frac{\text{Trips with Species}}{\text{Total Trips}} \times\right)}$$

We calculated the association statistic for all species reported by 100 or more fishing trips during 1997–2005. After calculating the association statistic, all trips were excluded from the 1997–2005 data set unless a trip kept or released a night shark or one of the top three species identified as an associate was kept or released. Bignose shark, *Carcharhinus altimus*, was calculated to have the highest associated statistic, followed by silky shark and scalloped hammerhead shark, *Sphyrna lewini*.

After refinement using the association statistic, night sharks were reported on 9.6% of all observed hauls. The effects of the following factors were considered in the generalized linear model: year, season, area, depth, bait type, hook type, and time of day. For the binomial model, year as a single fixed factor explained most of the deviance in the probability of catching at least one night shark. When modeling the positive trips, the factors year and depth explained the greatest deviance from the null model (Table 4). No interactions were found to be significant. The relative abundance based on bottom longline observer data indicated an increase in abundance (Fig. 4). Relative catch per unit effort increased from 0.31 (LCL=0.24, UCL=0.40) sharks per 100,000 hook hours in 1997 to 1.93 (LCL=1.80, UCL=2.01) sharks per 100,000 hook hours in 2005. Night sharks were not observed caught in 1999 or 2000.

Discussion

Several demographic and vulnerability criteria are considered when evaluating whether a species should be added, retained, or removed from the species of concern list. These criteria include distribution, including its natural rarity and endemism, abundance related to historic and recent magnitudes of decline, and life history characteristics, and productivity. We evaluated these criteria relevant to the night shark listing as a species of concern.

Distribution and Endemism

Night sharks do not appear to be naturally rare nor are they endemic to any discrete location in U.S. waters. An examination of all available data sources indicates night sharks are found along the outer continental shelf and upper slope areas throughout the Gulf of Mexico, in the northwest Atlantic Ocean as far north as Massachusetts, and in the Caribbean Sea (Fig. 5). Areas of concentration appear to be located off the east coast of Florida and South Carolina, and the Florida Straights, whereas night sharks are more uncommon in the Gulf of Mexico and in waters north of North Carolina (37°N latitude).

The distributional pattern of the night shark today appears to match well that of historical studies. Guitart-Manday

[11]Burgess, G. H. and A. Morgan. 2003. Commercial shark fishery observer program. Renewal of an observer program to monitor the directed commercial shark fishery in the Gulf of Mexico and south Atlantic:2002(2) and 2003(1) fishing seasons. Final Report, NMFS, Highly Migratory Species Manage. Div. Award NA16FM1598, 15 p.

[12]Cass-Calay, S. L., and M. Bahnick. 2002. Status of the yellowedge grouper fishery in the Gulf of Mexico: Assessment 1.0. NOAA, NMFS Sustain. Fish. Div. Contrib. SFD-02/03-172, 67 p.

[13]Cass-Calay, S. L., and T. W. Schmidt. 2003. Standardized catch rates of juvenile goliath grouper, *Epinephelus itajara*, from the Everglades National Park Creel Survey, 1973–1999. NOAA, NMFS, Sustain. Fish. Div. Contrib. SFD-2003-0016, 17 p.

(1975), Castro (1983), and Berkeley and Campos (1988) reported night sharks common in the southeast United States, especially in the Florida Straights. Early pelagic survey cruise records from the Gulf of Mexico rarely if ever reported the capture of night sharks (Bullis and Captiva, 1955, Wathne, 1959; Iwamoto, 1965). Recent scientific pelagic surveys in the Gulf of Mexico also report few captures ($n = 3$) of night sharks.[14]

Figure 5.—Distribution of observed night sharks captured from all scientific surveys and observer programs.

Characteristics and Productivity

Life History

A comparison of life history traits for other pelagic sharks indicates night sharks exhibit intermediate age and growth characteristics to those of other pelagic sharks (Table 5). For example, the blue shark, *Prionace glauca*, has been reported to have growth completion rates (i.e. Brody growth coefficient, K) of 0.13 yr^{-1}, age at maturity of 5.0 yr, and longevity of 6–16 yr (Skomal and Natanson, 2003). Night sharks displayed lower K values (0.11 yr^{-1}) and higher age at maturity (10 yr) and longevity (17 yr) estimates. These growth characteristics are closest to those exhibited by the silky shark (K = 0.10 yr^{-1}, age at maturity = 12 yr, longevity = 22 yr) among pelagic species.

In addition to life history characteristics, night sharks exhibit population parameters that fall between those of the blue and porbeagle, *Lamna nasus*, sharks. Night sharks can be placed in the upper-half along the "fast-slow" continuum of life history traits and population parameters for sharks identified by Cortés (2002: Fig. 2). The night shark has moderate rebound potential and an intermediate generation time. In addition, probabilistic elasticity analysis indicated that population growth rates of night sharks are more sensitive to survival of the juvenile and adult stages than to fecundity, as is common for many sharks. Analysis of life history data indicated night sharks population growth rates (r) are on the order of 10% yr^{-1} when life history estimates simulate a maximum compensatory response. In contrast, species like porbeagle and dusky sharks (also species of concern) have considerably lower levels of productivity ($r \approx$ 2–5% yr^{-1}). Recent stock assessments indicate populations of porbeagle and dusky sharks have declined by up to 90% and 80% from virgin biomass, respectively (Campana et al., 2002; Cortés et al.[15]).

Abundance

An analysis of trends in abundance from multiple data sources gave conflicting results. The single historic time series (NEFSC), spanning from 1961 to 1996, showed no clear trend in night shark relative abundance. Although this survey is long term, it came from areas that are primarily on the periphery of the night shark's range and likely do not represent core abundance estimates. The analysis of pelagic longline logbook data showed declines in relative abundance up to 55% since 1992. In contrast, the trend in abundance was positive for night shark from the pelagic longline observer program that samples the same universe of commercial fishing vessels although at a much reduced level (5–8%

[14]Cruise Results, 03/08/2005–04/06/2005, Pelagic Fish Longline Survey, NOAA Ship OREGON II, Cruise OT-05-02 (263), NMFS, Southeast Fish. Sci. Cent., Mississippi Lab., Pascagoula Facility, P.O. Drawer 1207, Pascagoula, MS 39568-1207, 15 p.

[15]Cortés, E., E. N. Brooks, P. Apostolaki, and C. A. Brown. 2006. Stock assessment of dusky shark in the U.S. Atlantic and Gulf of Mexico. NOAA, NMFS, Southeast Fish. Sci. Cent., Sustain. Fish. Div. Contrib. SFD-2006-014, 155 p.

Table 5.—A comparison of life history characteristics and population parameter estimates for the night shark derived in this study with those for other pelagic species. Values reported are for females. Age, growth, and reproductive information was summarized from studies by Castro and Mejuto (1995), Bonfil et al. (1993), Mollet et al. (2000), Lessa et al. (1999), Natanson et al. (2002), Jensen et al. (2002), Skomal and Natanson (2003), and Natanson et al. (2006). Productivity values are from Au et al. (In press) but may have used vital rates different from those listed here for calculation. All other values are from Cortés (in press).

Species	K (yr^{-1})	Longevity (yr)	Age at maturity (yr)	Fecundity (yr^{-1})	Generation time (T; yr)	Population growth rate (λ; yr^{-1})	Productivity ($r_{z=1.5M}$)
Night	0.11	17	10	5.5	13.8	1.10	0.021
Blue	0.13	16	6	18.5	8.4	1.25	0.060
Oceanic whitetip	0.09	11	4.5	3.1	11.1	1.07	0.066
Porbeagle	0.06	25	13	4.0	18.5	1.05	—
Shortfin mako	0.09	32	18	4.2	24.8	1.01	0.049
Silky	0.10	22	12	5.1	14.3	1.08	0.042

of total effort) compared to the pelagic logbook data. The trend in abundance from the bottom longline observer program also indicated an increase in relative abundance.

Linear regression analysis of each CPUE series on year shows that only two of the four series had statistically significant slopes (Table 6). The pelagic logbook series decreased about 9% per year, while the pelagic longline observer series increased about 9% per year. The NEFSC data decreased about 1% per year while the shark bottom longline observer increased about 20% per year, but neither of these trends was statistically significant.

Table 6.—Results of linear regression analysis on relative catch rates. S.E.= standard error.

Data set	Years	Slope	Slope S.E.	R^2	Significance F
NEFSC Laboratory Historical Longline Survey	1961–1996	–0.017	0.015	0.04	0.257
Commercial Pelagic Longline Logbook Program	1992–2005	–0.089	0.021	0.59	0.001
Pelagic Longline Observer Program	1994–2005	0.093	0.026	0.56	0.005
Shark Bottom Longline Observer Program	1997–2005	0.219	0.138	0.26	0.158

The changes in relative abundance obtained from the observer data could be the result of factors unaccounted for in the analysis. At the initiation of the pelagic longline observer program, observers reported very few night sharks, but many more were reported as the observer program developed. The increasing trend could be related to better observer identification skills as the program developed, whereas during the early years of the pelagic longline observer program observers were more likely to misidentify night sharks or report them as "unidentified sharks" (Beerkircher et al. 2002; Cortés et al., 2007). Similarly, increases in night sharks from the shark bottom longline observer program could be in part the result of changes in vessel selection. In the early years of the shark bottom longline program, observer coverage was voluntary, which limited the spatial and temporal sampling of animals caught in this fishery. After 2001, observer coverage became mandatory, and vessel selection increased to the entire sampling universe of the fishery.

Confusion over reporting practices, misreporting, and species misidentification could explain in part the decline in night sharks from the analysis of the pelagic logbook data. Before implementation of the first U.S. Atlantic Shark Management Plan in 1993, all fishermen targeting sharks or other pelagic longline fishermen targeting swordfish or tunas reported shark landings in the pelagic longline logbook. However, after implementation of the management plan, fishermen could temporarily report to a new logbook program designed for fishermen targeting sharks from 1993 to 1995. After 1995, fishermen again had the option to continue reporting to the pelagic longline program or to a coastal fisheries logbook program that also includes longline gear. There is also a tendency to under-report bycatch over time as fishermen develop a growing perception that those reports result in increasingly restrictive management regimes (Cortés et al., 2007). Additional factors that may have affected the analyses are confusion of night sharks with silky and dusky sharks, changes in hook size and type which are not reported in the logbooks, and fishing depth related to the tuna species targeted.

Despite the uncertainty and caveats associated with these analyses, night sharks are still a relatively common species. Information from the pelagic longline observer program indicates that night sharks are not rare and currently are the third-most abundant shark species captured in the pelagic longline fishery off the southeast United States (Beerkircher et al. 2002). Scientific survey operations in the western North Atlantic Ocean since 2004 also report the frequent capture of night sharks especially in areas off North Carolina.[16] Average size since the early 1980's has remained relatively stable suggesting that growth overfishing has not been occurring. Moreover, if we consider removing the first few years (e.g. 1992–93 for the pelagic logbook and 1994–95 for the pelagic observer programs) when uncertainties with reporting practices for logbooks and species identification may have occurred, the trend in abundance is relatively stable with some potential increases in night sharks in the pelagic observer data.

Conclusion

Night sharks are not naturally rare nor endemic to any discrete location in U.S. waters, have moderate rebound potential, and are among those sharks on the upper-half along the "fast-slow" continuum of life history traits and population parameters as described in Cortés (2002). Further, abundance

[16]Cruise Results, 02/01/2006-03/21/2006, Longline Survey Pelagic Sharks and Finfish, NOAA Ship OREGON II, Cruise OT-06-02 (269), NMFS, Southeast Fish. Sci. Cent., Mississippi Lab., Pascagoula Facility, P.O. Drawer 1207, Pascagoula, MS 39568-1207, 10 p.

data indicates night sharks have not suffered large magnitudes in decline. Thus, based on the analysis of all current available information, we believe the night shark should be removed from the NMFS species of concern list but retained on the prohibited species list as a precautionary approach to management until a more comprehensive assessment of the status of the stock can be conducted.

We recognize that the U.S population of night sharks is highly "conservation-dependent" and can be affected by fishing pressure, as is the case for populations of other pelagic and large-bodied coastal sharks. However, unless there is some major change in pelagic fishing effort or in the population's migratory patterns, the current protection afforded this species by the Consolidated Atlantic Highly Migratory Species Fishery Management Plan (NMFS, 2006) (i.e. prohibited species status) should ensure the species does not suffer any increased reduction in population size. Night shark landings were likely both over- and under-reported in the past and they probably do not reflect all commercial landings and overall have limited relevance to the current status of the species. However, landings data do provide corroborative evidence that in some cases the prohibited status of night sharks has reduced harvesting of the species since 2002.

Our conclusion is inconsistent with information presented in Castro et al. (1999), who reported a large decline (as a percentage of sharks caught) in night sharks since the 1930's and 1940's. Castro et al. (1999) also indicated that night sharks are currently rare off the southeast United States. However, much of the information presented in Castro et al. (1999) was from non-standardized catch information, and areas outside U.S. waters (e.g. northwest coast of Cuba). The reported declines could have been the result of local population reductions off Cuba, changes in fishing and marketing tactics, or problems with species identification. While it is likely that populations of night sharks have declined relative to virgin biomass, the magnitude of the decline is likely not as great as that indicated by Castro et al. (1999).

The use of relative abundance indices as indicators of population status for sharks without complete assessment models has been the subject of debate (Burgess et al. 2005a, b; Baum et al., 2005). In lieu of a full stock assessment, we have attempted to assess the status of night sharks using a combination of catch, catch rates, and productivity of the species. After careful examination of available information it is likely the available data, in particular catch data, are insufficient for a full stock assessment model. However, in data-poor situations, Porch et al. (2006) proposed the use of a "catch-free" stock assessment model that has been used for assessment of goliath grouper (Porch et al., 2006), blue sharks (ICCAT, 2004), shortfin makos (ICCAT, 2004), and dusky sharks (Cortés et al.[15]). Future research could attempt the application of a "catch-free" model for the assessment of night sharks. However, we feel the application of this model will likely result in high levels of uncertainty with potentially the same conclusion we have derived herein.

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Transboundary Movement of Atlantic Istiophorid Billfishes Among International and U.S. Domestic Management Areas Inferred from Mark-Recapture Studies

E. S. ORBESEN, J. P. HOOLIHAN, J. E. SERAFY, D. SNODGRASS, E. M. PEEL, and E. D. PRINCE

ABSTRACT—Billfish movements relative to the International Commission for the Conservation of Atlantic Tunas management areas, as well as U.S. domestic data collection areas within the western North Atlantic basin, were investigated with mark-recapture data from 769 blue marlin, Makaira nigricans, *961 white marlin,* Tetrapturus albidus, *and 1,801 sailfish,* Istiophorus platypterus. *Linear displacement between release and recapture locations ranged from zero (all species) to 15,744 km (mean 575, median 119, SE 44) for blue marlin, 6,523 km (mean 719, median 216, SE 33) for white marlin, and 3,845 km (mean 294, median 98, SE 13) for sailfish. In total, 2,824 (80.0%) billfish were recaptured in the same management area of release. Days at liberty ranged from zero (all species) to 4,591 (mean 619, median 409, SE 24) for blue marlin, 5,488 (mean 692, median 448, SE 22) for white marlin, and 6,568 (mean 404, median 320, SE 11) for sailfish. The proportions (per species) of visits were highest in the Caribbean area for blue marlin and white marlin, and the Florida East Coast area for sailfish. Blue marlin and sailfish were nearly identical when comparing the percent of individuals vs. the number of areas visited. Overall, white marlin visited more areas than either blue marlin or sailfish. Seasonality was evident for all species, with overall results generally reflecting the efforts of the catch and release recreational fishing sector, particularly in the western North Atlantic. This information may be practical in reducing the uncertainties in billfish stock assessments and may offer valuable insight into management consideration of time-area closure regulations to reduce bycatch mortality of Atlantic billfishes.*

Introduction

The istiophorid billfishes are large, highly migratory predators, whose range and movements encompass vast geographical areas. For instance, blue marlin, *Makaira nigricans*, and sailfish, *Istiophorus platypterus*, extend to tropical and subtropical waters worldwide, while white marlin, *Tetrapturus albidus*, range throughout the Atlantic Ocean.

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Owing to their highly migratory behavior, billfish stocks are often shared among many countries and, therefore, require regional and international management cooperation (Prince and Brown, 1991). In 1966, the International Commission for the Conservation of Atlantic Tunas (ICCAT) was established with a mandate to facilitate cooperative research, data collection, and management of tunas and tuna-like species (e.g. billfishes) within the Atlantic Ocean.

Over recent decades the landings of some Atlantic billfish species have decreased in size and number, a development largely attributed to increased commercial and recreational fishing activities (Restrepo et al., 2003). The most recent ICCAT stock assessments concluded that Atlantic blue marlin biomass is about 40% of the level required to produce maximum sustainable yield, while the situation for white marlin is more dire at about 20% (ICCAT, 2006). Sailfish numbers in the western North Atlantic are presently stable, but those in the eastern Atlantic appear to be decreasing (ICCAT, 2006). In the U.S. Atlantic management area, commercial harvesting of istiophorid billfish species has been prohibited since 1988. However, mortality resulting from incidental bycatch continues as multinational longline fisheries target tunas (Scombridae) and swordfish, *Xiphias gladius*, throughout the Atlantic (ICCAT, 2001; 2004).

Concerns for overexploitation and effective management of these highly migratory predators warrant a thorough understanding of their biology, ecology, and associated movement patterns. Mark-recapture studies using conventional streamer tags have assisted in defining the spatial and temporal characteristics for movement and migration of istiophorid billfish populations worldwide (Squire, 1972; Squire and Nielsen, 1983; Miyake, 1990; Pepperell, 1990a; 1990b; Scott et al., 1990; Van Der Elst, 1990; Prince et al., 2002; Hoolihan, 2003). Mather (1963), Bayliff and Holland (1986), McFarlane et al. (1990), and Prince et al. (2002) provide reviews and tagging technique information.

Conventional tagging of billfish in the United States was initiated in 1954, following development of in-water tagging techniques for large highly migratory species (Mather, 1963; Scott et al., 1990). At present, there are two major constituent-based tagging programs largely responsible for billfish mark-

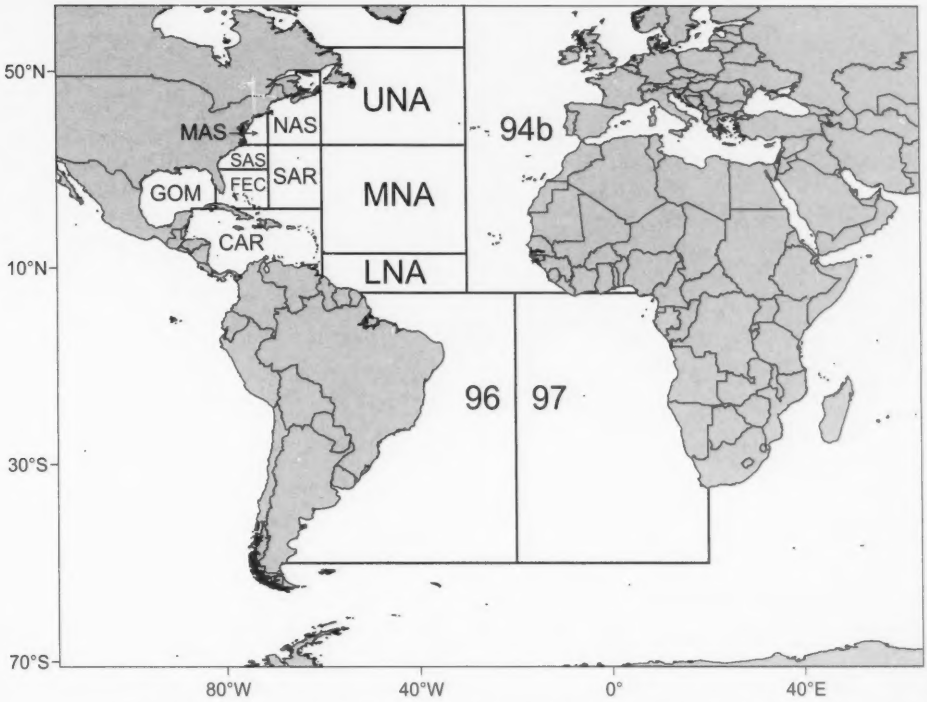

Figure 1.—ICCAT management areas and U.S. domestic submanagement areas used to evaluate movement of Atlantic billfish in this study.

recapture studies in the Atlantic–the Cooperative Tagging Center (CTC), based at NOAA's National Marine Fisheries Service (NMFS), Southeast Fisheries Science Center (Miami, Fla.), and The Billfish Foundation (TBF; Ft. Lauderdale, Fla.). Each program relies on volunteer tagging and recapture reporting by recreational and commercial fishermen.

Worldwide, from 1954 through 2005, these programs and their progenitors have documented the tagging of 266,448 istiophorid billfish. Recapture encounters have revealed Atlantic blue marlin completing transatlantic, transequatorial, and interoceanic movements, while white marlin have demonstrated transatlantic crossings (Ortiz et al., 2003). Sailfish generally remain closely associated with coastal zones having shallow continental shelves, although longline catch records do indicate a nominal presence in some mid-Atlantic offshore areas (Uozumi, 1996; Kim et al., 1998).

Table 1.—ICCAT Atlantic billfish management areas and associated U.S. domestic sub-management areas within ICCAT boundaries (Fig. 1, 2 show maps).

ICCAT Management Area	U.S. Domestic Sub-management Area
91	GOM = Gulf of Mexico
92	MAS = Mid Atlantic State, NAS = North Atlantic States, SAS = South Atlantic States, SAR = Sargasso, FEC = Florida East Coast
93	CAR = Caribbean
94a	UNA = Upper North Atlantic, MNA = Middle North Atlantic, LNA = Lower North Atlantic
94b	N/a
96	N/a
97	N/a

N/a = not applicable.

Currently, ICCAT recognizes single Atlantic-wide stocks for blue and white marlin based on mark-recapture studies and genetic evidence suggesting population mixing (ICCAT, 2006). For sailfish, separate eastern and western stocks are recognized and defined by a boundary loosely associated with the mid Atlantic Ridge (long. 40°W, North Atlantic; long. 20°W, South Atlantic); a decision based on distribution, morphology, genetic analyses, and mark-recapture data (ICCAT, 2006).

ICCAT has managed all Atlantic billfishes by separating presumed stocks along somewhat arbitrary boundaries falling within seven management areas used for statistical data collection purposes (Table 1, Fig. 1). Within some western ICCAT management areas, NMFS has further defined ten "U.S. domestic" subareas, which are targeted by

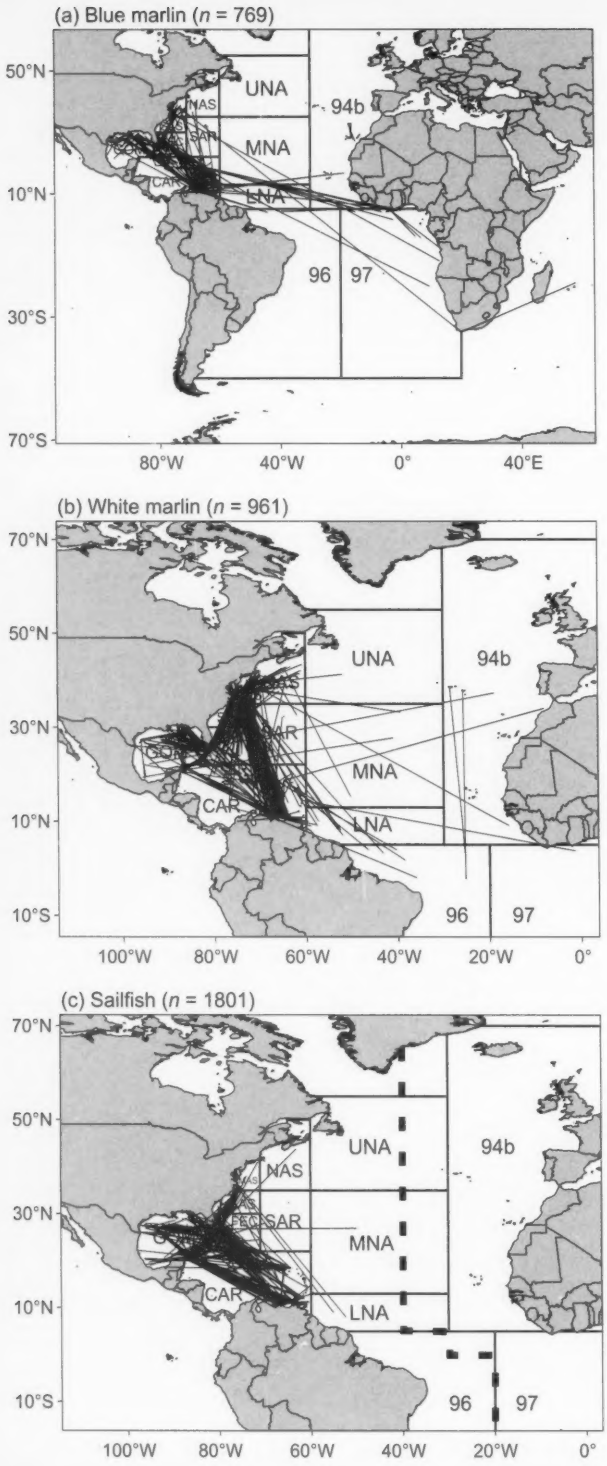

Figure 2.—Movement vectors of mark-recaptured blue marlin (a), white marlin (b), and sailfish (c), depicting shortest reasonable straight-line swimming routes. Specific indicators of release and recapture points have been omitted due to obscurity caused by multiple overlapping lines. Thick dashed line indicates east-west ICCAT stock boundary for sailfish.

U.S. recreational and commercial fleets and have a finer spatial resolution to suit NMFS requirements for data collection (Table 1, Fig. 1). Istiophorid billfish catches are relatively "rare" events, when compared to large-sized schooling scombrids (Prince and Brown, 1991). Therefore, partitioning data sampling areas into finer-scaled subunits should enhance our comprehension of the spatial distribution and movement patterns of Atlantic billfishes.

Our study was conducted to analyze currently available CTC and TBF mark-recapture data to define and quantify movement patterns and seasonality of Atlantic blue marlin, white marlin, and sailfish in association with ICCAT management areas and U.S. domestic subareas, a relationship not addressed in previous mark-recapture reports. Using mark-recapture data to identify the temporal and spatial distribution of billfish in relation to these management areas can further our understanding of stock structure and migration characteristics that help define essential habitat. In terms of management, this information provides insight into areas of peak abundance, which in turn may lead to reducing uncertainties in stock assessments. This information will also benefit management relative to time-area closure considerations, a method proposed as a means to reduce billfish bycatch mortality (Goodyear, 1999).

Methods

We assessed movements of Atlantic istiophorid billfishes among ICCAT and U.S. domestic management areas (Table 2, Fig. 2) using conventional tagging data compiled during 1954–2005 for blue marlin (released = 51,473, recaptured = 769), white marlin (released = 47,662, recaptured = 961), and sailfish (released = 91,125, recaptured = 1,801). Days at liberty, displacement distance moved (km), and transboundary cross-

Table 2.—Releases of blue marlin, white marlin, and sailfish by management area (left column), and their respective recapture areas (top row). Dashes indicate none. No recaptures occurred in area 96.

Release area	Species	Total releases	Recapture Area													Total
			CAR	FEC	GOM	MAS	MNA	NAS	UNA	SAS	SAR	LNA	94B	96	97	
CAR	Blue marlin	28,707	562	4	6	1	4	3	—	—	1	7	4	2	10	604
	White marlin	15,086	412	1	7	5	1	2	—	1	—	3	1	3	1	437
	Sailfish	29,867	289	28	45	1	—	1	—	1	—	—	—	—	—	365
FEC	Blue marlin	7,108	18	17	12	3	1	—	—	—	—	1	—	—	—	52
	White marlin	2,871	9	2	7	11	—	4	—	1	—	—	—	1	—	35
	Sailfish	52,640	48	1,259	56	1	—	—	—	5	1	—	—	—	—	1,370
GOM	Blue marlin	7,084	7	5	47	1	—	—	—	—	—	—	—	—	—	60
	White marlin	7,526	10	7	63	10	—	1	—	—	—	—	—	—	—	91
	Sailfish	4,293	8	16	8	—	—	—	—	—	—	—	—	—	—	32
MAS	Blue marlin	1,556	1	1	1	2	—	—	—	4	—	—	—	—	1	10
	White marlin	18,231	78	31	23	188	1	28	1	9	5	5	—	1	—	370
	Sailfish	894	2	10	1	3	—	—	—	—	—	1	—	—	—	17
MNA	Blue marlin	117	1	—	—	—	—	1	—	—	—	—	—	—	—	2
	White marlin	140	—	—	—	—	—	1	—	—	—	—	—	—	—	1
	Sailfish	37	—	—	—	—	—	—	—	—	—	—	—	—	—	0
NAS	Blue marlin	128	—	1	—	—	—	—	—	1	—	—	—	—	—	2
	White marlin	1,648	1	3	—	7	—	3	—	—	1	—	—	—	—	15
	Sailfish	30	—	—	—	—	—	—	—	—	—	—	—	—	—	0
UNA	Blue marlin	21	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	White marlin	43	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	Sailfish	5	—	—	—	—	—	—	—	—	—	—	—	—	—	0
SAS	Blue marlin	1,083	4	5	—	3	—	—	—	—	—	—	—	—	—	12
	White marlin	876	2	—	1	3	—	—	—	1	—	—	—	—	—	7
	Sailfish	1,187	3	10	1	1	—	—	—	1	—	1	—	—	—	17
SAR	Blue marlin	1,243	1	1	—	—	—	—	—	—	2	—	—	—	—	4
	White marlin	332	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	Sailfish	44	—	—	—	—	—	—	—	—	—	—	—	—	—	0
LNA	Blue marlin	67	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	White marlin	23	1	—	—	—	—	—	—	—	1	—	—	—	—	2
	Sailfish	20	—	—	—	—	—	—	—	—	—	—	—	—	—	0
94B	Blue marlin	3,531	—	—	—	—	1	—	—	—	—	—	16	1	1	19
	White marlin	673	—	—	—	—	—	—	—	—	—	—	1	2	—	3
	Sailfish	995	—	—	—	—	—	—	—	—	—	—	—	—	—	0
96	Blue marlin	493	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	White marlin	204	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	Sailfish	695	—	—	—	—	—	—	—	—	—	—	—	—	—	0
97	Blue marlin	335	—	—	—	—	—	—	—	—	—	—	1	—	2	3
	White marlin	9	—	—	—	—	—	—	—	—	—	—	—	—	—	0
	Sailfish	418	—	—	—	—	—	—	—	—	—	—	—	—	—	0

ings of ICCAT and U.S. domestic management areas were determined. Most of the releases occurred in western North Atlantic waters. A few blue marlin and white marlin were marked and released in the eastern Atlantic, but no sailfish. Distance moved was assumed to be the shortest reasonable and direct swimming path between release and recapture locations, calculated as a great-circle arc vector (Earle, 2005). Many of the vectors implied minor land crossings (e.g. Caribbean islands). We opted not to reroute these through adjacent waterways because the change in distance traveled would have been negligible, and the selection of alternate directional paths was considered too arbitrary.

Upon considering Atlantic billfish movement among the 17 management areas (ICCAT, 7; U.S., 10), our preference was to defer (when possible) to the smaller U.S. domestic submanagement areas, which provided a finer spatial scale (Table 1). Therefore, releases and recaptures occurring within U.S. domestic areas were indicated as such, while those outside U.S. domestic areas were assigned to their respective ICCAT areas. Where several U.S. domestic submanagement areas comprise an ICCAT area, that ICCAT area was ignored. This merging procedure reduced our analysis and reporting to a total of 13 management and submanagement areas (Fig. 1) that included ICCAT management areas 94b, 96, 97; and, the U.S. domestic submanagement areas for the Gulf of Mexico (GOM), Mid Atlantic States (MAS), North Atlantic States (NAS), South Atlantic States (SAS), Sargasso (SAR), Florida East Coast (FEC), Caribbean (CAR), Upper North Atlantic (UNA), Middle North Atlantic (MNA), and Lower North Atlantic (LNA).

Hereafter, we apply the term "area" to both management and submanagement areas. "Visit" is defined as release and recapture within the boundaries of a particular area. Visits (putative) were also deemed to have occurred in other management areas falling on a straight line between the release and recapture locations of each tagged fish. Notably, this imposed limitations, since actual swimming tracks are unknown. For individuals released and recaptured in the same area, a single visit was assigned. To derive seasonality, we used release and recapture visits, compiled by month and area, to determine where and when major activity occurred.

Results

Linear displacement (km) between release and recapture locations ranged from zero (all species) to 15,744 for blue marlin, 6,523 for white marlin, and 3,845 for sailfish. The mean displacements (km) were: 575 (median 119, SE 44) for blue marlin, 719 (median 216, SE 33) for white marlin, and 294 (median 98, SE 13) for sailfish. In total, 2,824 (80.0%) individuals were recaptured in the same management area where released. Days at liberty (DAL) ranged from zero (all species) to 4,591 (12.6 yr) for blue marlin, 5,488 (15.0 yr) for white marlin, and 6,568 (17.9 yr) for sailfish (Fig. 3). The mean DAL values were: 619 (median 409, SE 24) for blue marlin, 692 (median 448, SE 22) for white marlin, and 404 (median 320, SE 11) for sailfish. The proportion of visits (per species) were highest in CAR (blue marlin and white marlin), and FEC (sailfish, Fig. 4). Blue marlin and sailfish were nearly identical when comparing the percent of individuals versus the number of areas visited (Fig. 5). Overall, white marlin visited more areas than either blue marlin or sailfish (Fig. 5).

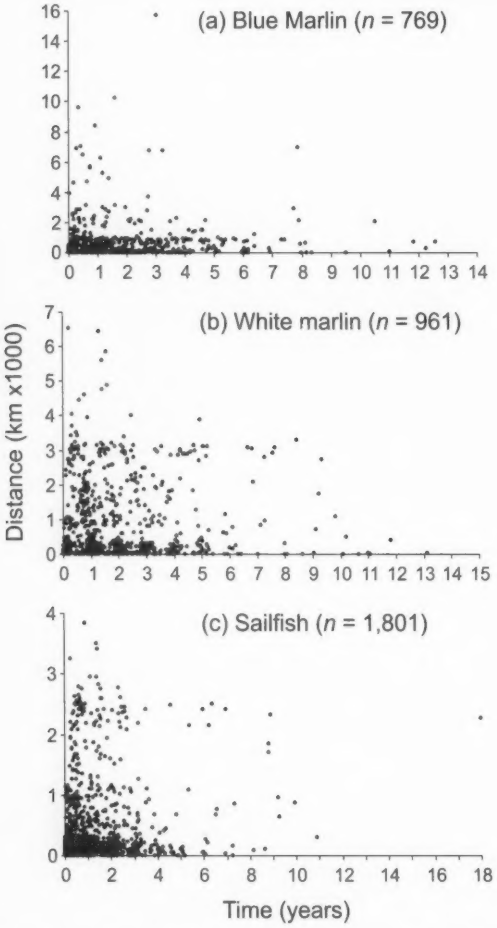

Figure 3.—Distance traveled, in relation to time at large, for mark-recaptured Atlantic blue marlin (a), white marlin (b), and sailfish (c). Distances were calculated as great-circle arc vectors between release and recapture locations.

Blue marlin were associated with all areas except UNA. The number of areas visited by individuals ranged from one to seven (mean 1.30). Of the 769 mark-recaptured blue marlin, 640 (83.2%) were released and recaptured in the same area. The ratio of single area visits to putative visits to other areas between points of release and recapture was 1.88:1. The largest proportion of activity was observed in CAR, which accounted for 64.4% of the total visits to all management or submanagement areas (Fig. 2). Moreover, CAR had the highest number of releases, accounting for 605 (78.7%) specimens. Of these, 562 (92.9%) were also recaptured in CAR. Eighteen blue marlin conducted long distance movements that were transatlantic (i.e. crossing the mid Atlantic Ridge), transequatorial, or both (Fig. 2). One exceptional individual, previously reported by Ortiz et al. (2003), released in MAS, completed transatlantic, transequatorial, and interoceanic movements before being recaptured in the Indian Ocean (Mauritius).

Visits by white marlin were recorded in all the 13 areas included in our study (Fig. 2), while a total of 640 (66.6%) were recaptured in the same area where released. The number of areas visited by individuals ranged from one to seven (mean 1.78), while the ratio of single area visits to putative visits to other areas between points of release and recapture was 0.59:1 Four submanagement areas (CAR, MAS, FEC, and SAS) accounted for 80.0% of all visits. Most of these were released or recaptured inside CAR (31.8%) and MAS (24.0%). Visits to FEC and SAS were largely attributed to transboundary crossings during travel between points of release and recapture from other areas. Two individuals made southerly transequatorial crossings terminating in area 96, representing the first documented transequatorial crossings by white marlin. One originated from CAR and the other from area 94b (Table 2, Fig. 2). These, plus movements of six additional white marlin extended south of lat. 5°N. Five individuals conducted eastward transatlantic crossings, but no interoceanic movements were observed.

Sailfish visited nine areas in total, and were absent from UNA, 94b, 96, and 97 (Fig. 2). The number of areas visited by individuals ranged from one to six (mean 1.19). A total of 1,544 (85.7%) were recaptured in the same area where released. The ratio of single area visits to putative visits to other areas between points of release and recapture was 2.58:1. The area with the greatest proportion (67.9%) of combined visits was FEC. No sailfish were observed making transequatorial, transatlantic, or interoceanic movements. Moreover, no sailfish crossed the boundary line (long. 40°W, North Atlantic; long. 20°W, South Atlantic) used by ICCAT to differentiate between eastern and western stocks. Sailfish seasonality was apparent for many individuals released in FEC during the peak abundance period (winter-spring); then subsequently recaptured (mostly during the summer) after dispersing to other areas (Fig. 6).

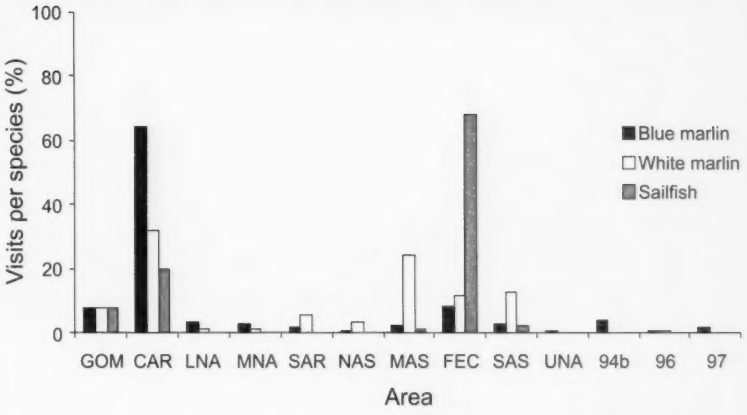

Figure 4.—Occurrence (%), by species, in management areas for blue marlin, white marlin, and sailfish, based on reasonable linear displacement between release and recapture locations.

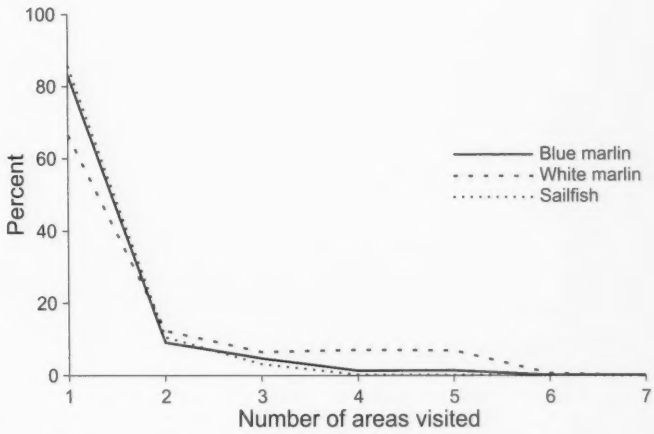

Figure 5.—Percent of visits (by species) for blue marlin, white marlin, and sailfish per management or submanagement area, based on reasonable linear displacement between release and recapture locations.

Discussion

Much of what is currently understood about the behavior of Atlantic billfishes is derived from conventional mark-recapture efforts. Large numbers of tags deployed over a lengthy period (1954–present) have provided details of movement, range, and longevity that would have been difficult to assess otherwise. Although highly successful, conventional mark-recapture techniques have inherent characteristics that restricted the scope of analyses in our study. For instance, the absence of spatial positioning details (i.e. continuous track path) limited our interpretation of movement to direct linear displacement between points of release and recapture. In contrast, studies monitoring billfish with pop-up satellite tags (PSAT's) revealed that individuals are more likely to meander across large areas, rather than moving in a unidirectional manner (Gunn et al., 2003; Prince et al., 2006). For that reason, the number of areas visited by individuals in our study was probably underestimated.

In addition, our analyses lacked the temporal details of transboundary crossings, a problem further confounded by multiseasonal periods between release and recapture for some billfish. When assigning visit status to various management areas, we were unable to recognize multiseasonal (> 1 yr) movements for most individuals. For example, a sailfish released and recaptured in FEC after 800 DAL was assumed to have remained inside FEC for the full period. The opposite scenario (leaving FEC) is more likely, as this fishery exhibits seasonal abundance variation that is probably a reflection of migratory movement (associated with spawning and foraging behavior) between various locations. Hence, the number of visits calculated for the three species examined is undoubtedly low. Despite these shortcomings, linear tracks offered the best available information and provided estimates for the minimal number of areas encountered by an individual before recapture.

The movements of Atlantic blue marlin, white marlin, and sailfish, derived from the conventional tag recaptures, support the currently accepted ICCAT boundary definitions for delineating stock structure. For example,

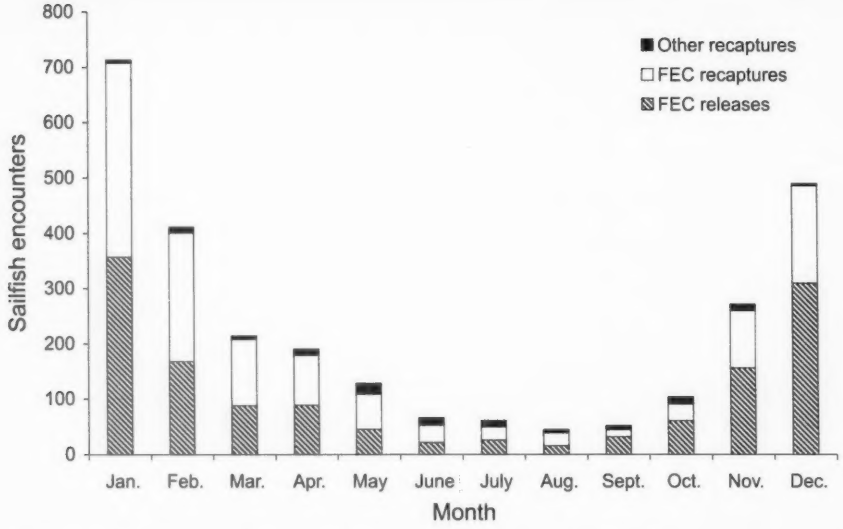

Figure 6.—Total encounters by month for sailfish released in FEC area and subsequently recaptured in FEC and other areas. Recaptures outside FEC suggest seasonal movement.

sailfish exhibited no transboundary movements across the putative boundary lines (long. 40°W, North Atlantic; long. 20°W, South Atlantic) separating eastern and western stocks. In turn, the data also supported single Atlantic-wide stocks for blue marlin and white marlin. Both species exhibited movement across lat. 5°N, the line previously used by ICCAT to differentiate between north and south stocks, although there were few of these examples. However, the spatial distribution of tagging effort throughout the Atlantic was very uneven, a factor probably contributing to the low number of examples.

The currently available information on the genetic stock structure of Atlantic blue marlin, white marlin, and sailfish suggests an absence of within-Atlantic divergence, thereby supporting the likelihood of single stocks for all three species (Graves and McDowell, 1998; 2001). Notably, a few intermingling fish per generation are capable of reducing heterogeneity to a level where genetic population structure is indiscernible (Carvalho and Hauser, 1994). So, while minimal mixing is apparent, it does not necessarily exclude the presence of multiple stocks. Analyses of additional molecular markers may reveal further stock structure.

Distinguishing the presence of multiple stocks also requires a more comprehensive understanding of Atlantic billfish movements. This is particularly relevant for the eastern and southern Atlantic regions, where tagging effort and recapture data are very sparse. Increased tagging effort in these regions is warranted. However, since there is not a well established infrastructure for recreational tag and release in eastern and southern Atlantic regions, in contrast to the western North Atlantic, the deployment of pop-up satellite archival tags may be a more efficient alternative for acquiring more comprehensive and detailed movement information.

Seasonal residency for some management areas was evident from the distribution of mark-recapture data. For white marlin, this was apparent in the MAS area (Fig. 7), where summertime aggregating behavior has been recognized since 1935 (Earle, 1940). Examination of gonads by de Sylva and Davis (1963) showed white marlin moving into MAS in late summer were in post-spawning condition. Subsequent reproductive studies indicated pronounced spawning activity taking place in CAR during April–July (Baglin, 1979; Prince et al., 2005; Arocha et al., 2007). This, plus the relatively high exchange of tagged white marlin between CAR and MAS (Fig. 2), suggests that the seasonal movement to MAS represents a post-spawning foraging migration. Whether the white marlin movements between MAS and CAR are direct, or take more circuitous routes (e.g. via GOM or mid-Atlantic routes), is unclear. However, this is a relevant research question to address. Some recaptures in GOM did occur from both MAS and CAR releases (Table 2); however, this is not necessarily representative of the total population, as movement patterns may vary between sexes, subpopulations, or age groups.

Sailfish released in the FEC exhibited seasonal variation suggesting migratory behavior. Although sailfish releases and recaptures were recorded in every month for the FEC, the majority were concentrated between late fall and early spring, clearly reflecting the seasonality of the recreational fishery. Here, it seems seasonal migration is the norm for this particular population, based on the spatial and temporal characteristics of the recaptures. For example, sailfish

released in FEC, but recaptured elsewhere, were mostly recaptured during the summer and not during the period (winter–spring) normally associated with peak abundance in the FEC (Fig. 6). A similar seasonal migration timing was reported by Hoolihan (2003) for sailfish in the Arabian Gulf, using similar mark-recapture techniques.

Sailfish exhibited the maximum time at large (~ 18 yrs.) for the three species in our study, greatly exceeding the maximum age limit estimates from otolith and fin spine studies (Hedgepeth and Jolley, 1983; Prince et al., 1986; Hill et al., 1989; Wilson et al., 1991). Although mark-recapture programs are unable to estimate maximum age, they do provide useful estimates of minimal longevity.

With respect to maximum distances traveled, blue marlin exhibited more cosmopolitan behavior than the other species in our study (Fig. 2, 3). Such extraordinary great distances have also been reported for the Indo-Pacific black marlin, *Makaira indica*, a species of similar somatic size to blue marlin (Ortiz et al., 2003). However, when considering the number of areas visited, white marlin exhibited a ratio of 0.59:1 for single area visits vs. putative visits to other areas between points of release and recapture, clearly exceeding blue marlin (1.88:1) and sailfish (2.58:1). The fact that sailfish showed a higher affinity for remaining in the same area is not surprising considering their close association with coastal areas.

Use of time-area closures has been shown, in theory, to be a feasible method of reducing longline bycatch mortality of Atlantic billfish (Goodyear, 1999); and, may be an increasingly important approach to rebuilding depleted stocks of Atlantic billfish. The results of the present study enhance existing knowledge regarding distribution, aggregation behavior, and transboundary movements for Atlantic istiophorids that would benefit management planning for time-area closures. For example, mark-recapture information for seasonality and aggregation of white marlin, in relation to spawning activity, would be an important consideration if time-area closures were instigated to protect critical habitat for this overexploited species.

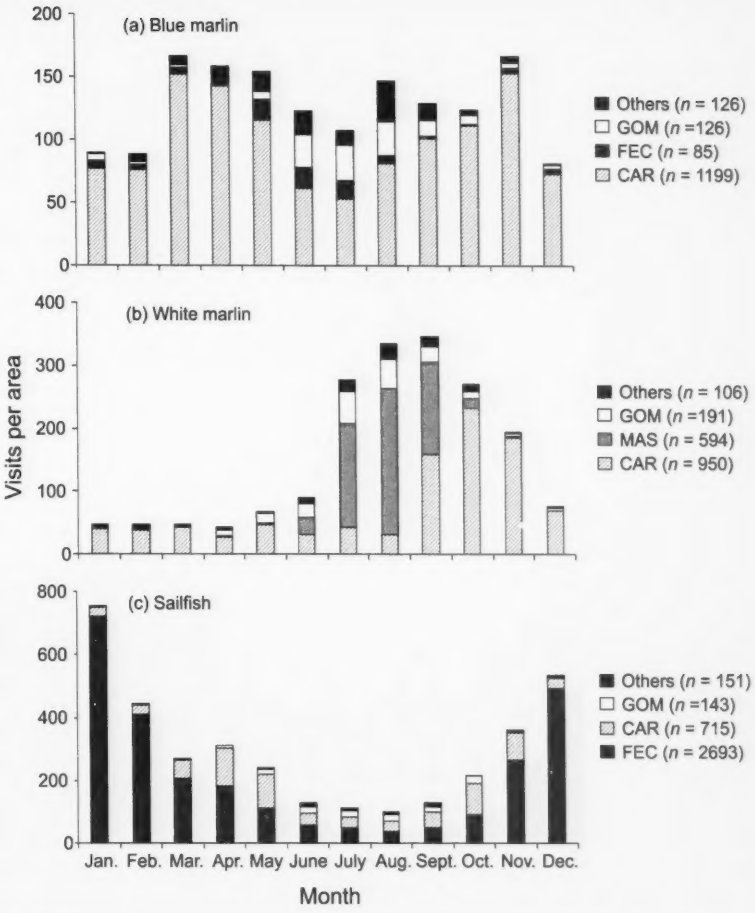

Figure 7.—Number of visits per month by mark-recaptured Atlantic blue marlin (a), white marlin (b), and sailfish (c) to ICCAT management areas and U.S. domestic submanagement areas. One "visit" was assigned to each area of release and recapture. Individuals released and recaptured in the same area were assigned a single visit only. The majority of visits occurred in the U.S. domestic sub-management areas GOM (Gulf of Mexico), FEC (Florida East Coast), MAS (Mid Atlantic States), and CAR (Caribbean). The remainder of visits to other areas were pooled in the group "others" (Table 2 shows releases and recaptures by area).

The spatial distribution of mark-recaptured Atlantic billfish presented in our study reflects the successes, and limitations, of a constituent based conventional tagging program (Ortiz et al., 2003). Releases primarily occurred in the western North Atlantic, reflecting the long-term popularity of recreational tag and release fishing in the domestic U.S. submanagement areas. Additionally, nearly all of the mark-release events took place near coastlines, a factor influenced by vessel limitations and trip durations typical of the recreational fishery. Given these limitations, it should be noted that the recreational billfish fishery of the western North Atlantic is extensive and long standing. As such, this suggests that the conventional tagging data offers a reasonable representation of the temporal and spatial coastal abundance for these

species. In other words, it is unlikely that the seasonal or geographical occurrence of large numbers of billfish have eluded the recreational fleet.

The CTC and TBF conventional tagging programs have provided useful information about Atlantic billfish movement and migration. At the same time, these programs have formed an association between scientists and recreational fishermen, providing valuable information on local fisheries. Shortcomings in the conventional tagging programs have highlighted two points warranting further investigation. Firstly, enlarging the scope of the tagging effort to include a more comprehensive coverage of the eastern and southern Atlantic billfish habitat is needed. This may present a problem, as these areas lack the active catch and release recreational fisheries that are so prevalent in the western North Atlantic. ICCAT's enhanced research program for billfish, originally developed in 1986 (Prince et al., 1987), included an objective to accomplish more mark-recapture activities in the East Atlantic. However, progress on this objective has been slow to develop.

Secondly, the obvious lack of spatial positioning during DAL when using conventional tags prevents an accurate assessment of track path, or management area usage. Both of these concerns can be ameliorated with well designed PSAT studies. PSAT units can provide track path estimates based on light level geolocation algorithms, thus providing a more realistic portrayal of billfish movement tracks (Arnold and Dewar, 2001). Because PSAT's are "fisheries independent" (i.e. do not require recapture), far fewer are needed in comparison to conventional tags.

The efficacy of using PSAT's to determine movements of large pelagic species is well established (for review, see Arnold and Dewar, 2001). One example is the recent work of Prince et al. (2006), whereby PSAT data from 41 sailfish were used to describe transboundary movements on the Pacific side of central America. However, PSAT's have their own inherent drawbacks and are unlikely to match some of the larger spatial and temporal displacements divulged by conventional tagging. Presently, PSAT's are costly, and they have not proved suitable for long-term monitoring of multi-seasonal behavior. Many of the more interesting long-term displacements, revealed with conventional tags (Fig. 2), would be unobtainable using pop-up satellite tags. We suggest that greater advances will come about if billfish PSAT studies are integrated within the domain of conventional tagging programs, so their respective datasets can complement one another.

Acknowledgements

Appreciation is extended to C. Rivero and D. Bogardus for assistance in extracting the necessary information from the CTS and TBF databases. We would like to acknowledge the volunteer efforts of all recreational and commercial constituents who have participated in the billfish tag and release programs and to the various financial donors who have contributed to the success of these programs.

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Stanford University's John Otterbein Snyder: Student, Collaborator, and Colleague of David Starr Jordan and Charles Henry Gilbert

MARTIN R. BRITTAN and MARK R. JENNINGS

Introduction

For 80 years, beginning in 1891—the year that U.S. senator Leland Stanford's university opened under the leadership of its new president, David Starr Jordan (1851–1931)—there flourished such a productive and distinguished group of ichthyologists and fisheries biologists in the Department of Zoology, that they were known as the "Stanford School of Ichthyology." (Brittan, 1997). Many of his newly hired faculty, chief among them Charles Henry Gilbert (1859–1928) (Dunn, 1997), had been students and, later, colleagues of Jordan when he had been professor and president at Indiana University from 1885 to 1891.

Of the earliest Stanford students, two who soon became members of the Stanford zoology faculty were John Otterbein Snyder (1867–1943; Fig. 1) and Edwin Chapin Starks (1867–1932). Although a considerable amount has been written about Jordan and Gilbert and their students (Jordan, 1922; Myers, 1951; Brittan, 1997; Dunn, 1997), virtually nothing has been written about Snyder save three short obituaries in scientific journals that appeared soon after his death (Hubbs, 1943; Rich, 1943; Taft, 1944). In this paper, we describe some of Snyder's fisheries work, both in marine and freshwater environments, and his collaboration with Stanford faculty and students. In doing so, we hope to provide an idea of the mixing and exchange of people and ideas at Stanford University that provided the solid basis for our understanding of regional fish faunas in parts of the Pacific Ocean and the American West.

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ABSTRACT—John Otterbein Snyder (1867–1943) was an early student of David Starr Jordan at Stanford University and subsequently rose to become an assistant professor there. During his 34 years with the university he taught a wide variety of courses in various branches of zoology and advised numerous students. He eventually mentored 8 M.A. and 4 Ph.D. students to completion at Stanford. He also assisted in the collection of tens of thousands of fish specimens from the western Pacific, central Pacific, and the West Coast of North America, part of the time while stationed as "Naturalist" aboard the U.S. Fish Commission's Steamer Albatross *(1902–06). Although his early publications dealt mainly with fish groups and descriptions (often as a junior author with Jordan), after 1910 he became more autonomous and eventually rose to become one of the Pacific salmon,* Oncorhynchus *spp., experts on the West Coast. Throughout his career, he was especially esteemed by colleagues as "a stimulating teacher," "an excellent biologist," and "a fine man."*

Biographical Overview

Snyder, like so many of Jordan's early students, was a native Indianan (born in Butler on 14 Aug. 1867) and received his early education in the state (Hubbs, 1943; Rich, 1943). Upon his graduation from high school in 1888, he taught public school for 2 years at Cedar Lake, Ind., but soon after decided to further his education (Anonymous, 1943). Thus, after a year as a student at the University of Indiana during 1890–91, he followed Jordan to Stanford as an undergraduate student (Rich, 1943). Snyder attended Stanford during 1892–93 (Fig. 2), was Superintendent of Schools at Pullman, Wash., from 1893 to 94 (to earn money for his undergraduate education), and again was a student at Stanford during 1894–97 (Anonymous, 1910; 1943). He graduated with a Bachelor of Arts degree in 1897, and soon after, was awarded the Master of Arts degree in 1899, with Gilbert as his major professor (Brittan, 1997).

Jordan had immediately appointed Gilbert as head of the department in 1891, upon the opening of the university, a position he held for 34 years until he retired in 1925, to be succeeded by Snyder (after the latter's 1-year stint as Director of the U.S. Bureau of Fisheries Laboratory at Woods Hole, Mass.), who served until his own retirement in October 1931 (Brittan, 1997). The hiring of Snyder to replace Gilbert was apparently hastened as a result of Gilbert's ill health due to overwork from his many university duties and government research studies (Dunn, 1997)

After Snyder's university retirement, he was named Chief of the Bureau of Fish Propagation for the California Division of Fish and Game, in charge of all of California's trout and salmon hatcheries (Anonymous, 1943; Taft, 1944). Under Snyder's leadership a number of river surveys were carried out, and the bureau expanded to become the Bureau of Fish

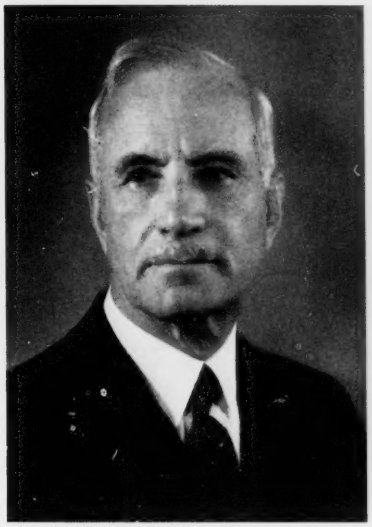

Figure 1.—John Otterbein Snyder, ca. 1935. Original photo courtesy of Stanford University Archives.

Figure 2.—John Otterbein Snyder and some classmates at Stanford University during the 1893–94 academic year. They are (from left in lower row): Walter Robert Shaw, DeAlton Saunders, Stewart Daniel Briggs, Charles J. Pierson, Frank Jotham Snow, William Appleton "Dick" Snow, and William Freeman Snow; from left in upper row: Cloudsley Louis Rutter, John Otterbein Snyder, three unidentified women, John Adams Colliver, Ray Lyman Wilbur, Edwin Lincoln Reichenbach (surname changed to "Russell" during World War I), and Richard Crittenden McGregor. The original caption reads: "And they all laughed." Original photo courtesy of Richard R. Rutter.

Conservation. In ill health, Snyder retired in 1937, and he died on 19 August 1943 at age 76 (Taft, 1944).

Field Work

Jordan had long been an organizer of collection expeditions, using students, many of whom, like Gilbert, Barton Warren Evermann (1853–1932), Seth Eugene Meek (1859–1914), and Carl "H." Eigenmann (1863–1927), later became well-known ichthyological colleagues (Hubbs, 1964). During 1896–97 Jordan took young Snyder with him to collect specimens in central México, and in 1900 they went to the Hawaiian Islands and Japan, making very large collections (Jordan, 1922). This work was perhaps the first extensive use of Formalin in the field to preserve fishes (Brittan, 1997).

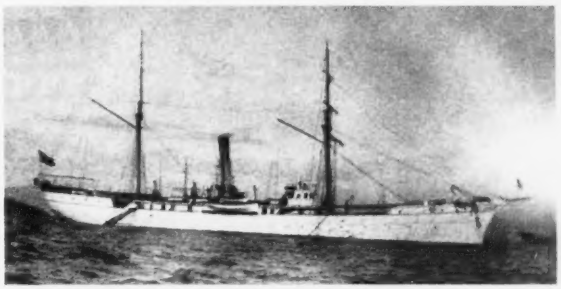

Figure 3.—The Fisheries Steamer *Albatross* in Alaska waters near Kodiak Island in May 1903. Original photo courtesy of Richard R. Rutter.

In 1902 came the first of the many trips made by Stanford ichthyologists on the U.S. Fish Commission's steamer *Albatross* (Fig. 3), this to the Hawaiian and Laysan Islands; in the huge collections were 210 new species, later described by Gilbert (Dunn, 1996a; 1997). The *Albatross*, in 1906, subsequently made a trip to Japan, the Ryukyus, Kamchtatka, and the Aleutian Islands, with Gilbert, Snyder, and Walter Kenrick Fisher (1878–1953) aboard, again making large collections (Dunn, 1996b; Jordan, 1922).

The *Albatross* cruises, with many of the trips staffed by Stanford scientists (during which time Snyder was appointed as "Naturalist" to oversee the collection and preservation of vast numbers of fish specimens), were financed by the U.S. Fish Commission and the U.S. National Museum, with the latter receiving the primary type material and some secondary type material, as well as much nontype material and Stanford getting

secondary types and some primary types (out the cotype-syntype series), and a substantial part of the remainder. Both the U.S. National Museum and Stanford University exchanged specimens with other museums from around the world (Brittan, 1997). Snyder's appointment as Naturalist aboard the *Albatross* during 1902–06 brought him in close collaboration with the Resident Naturalist of the ship (the individual responsible for managing the daily activities of scientific studies conducted on board or delegated field work on shore such as salmon spawning stream surveys or freshwater fish collections)—established government scientists such as Henry Frank Moore (1867–1948), Cloudsley Louis Rutter (1867–1903), and Frederic Morton Chamberlain (1867–1921) (Hedgpeth, 1945; Jennings, 1987). Interesting enough, Rutter was actually a classmate of Snyder's at Stanford and received some wise instruction and counsel from Snyder on collecting scientific specimens while Rutter was working on Kodiak Island in Alaska during 1896–97 (Anonymous, 1896; Jennings, unpubl. data).

The work by Snyder and others aboard the *Albatross* cannot be underestimated, especially in light of the breadth and depth of natural history specimens collected in the east and west Pacific Ocean that are now housed in various museums. Their labors were physically demanding, not only from handling sampling gear under harsh environmental conditions and outbreaks of sea sickness which negatively affected many visiting scientists on board (Dunn, 1996a; Jennings, 1997), but also from the long hours sorting and preserving fish specimens, the many nighttime fish collections, and the sampling of specific transect stations conducted throughout the day and night (Bartsch, 1941). The loss of nets, trawls, dredges, and other sampling gear was not uncommon, although some of this gear was experimental and thus vulnerable to damage or loss (Jennings, 1987).

Further, there were often tensions on board between the naval officers in charge of the *Albatross* and the civilian scientists assigned to the vessel (Hedgpeth, 1945; Dunn, 1996a; 1996b). During the 1980's and 1990's, additional tensions and conflicts have been discovered between the scientists themselves on the vessel (Jennings, 1987; Dunn, 1997; Jennings, unpubl. data). Such interactions can be expected by groups of people in such close contact day after day, with long hours working under very strenuous conditions and a tight budget and sampling schedule. Fortunately, Snyder's ever positive personality allowed him to avoid these challenges and, instead, focus his energies on collecting, preserving, and identifying new species of fishes.

In 1904, Snyder and Starks made a long trip by horseback to the lakes and streams of northeastern California and southeastern Oregon. This was the beginning of Snyder's extensive investigations of the fishes of California and other parts of the American West, and this continued for the rest of his life (Taft, 1944).

In 1909, Gilbert, Snyder, and Starks surveyed the streams entering Monterey Bay and, in 1911, Snyder and Charles Howard Richardson, Jr. (1887–1977), collected in the Lahontan Basin of Nevada and northeastern California (Böhlke, 1953). Snyder, assisted by the young Carl Leavitt Hubbs (1894–1979), later to become the "Grand Old Man of American Ichthyology," worked on the Lahontan cutthroat trout, *Oncorhynchus clarkii henshawi*, of Pyramid Lake, Nev., and its tributary Truckee River, flowing out of Lake Tahoe, on the California-Nevada border, in 1915 and 1916 (La Rivers, 1962). It was during this work (in the summer of 1915) that Snyder and Hubbs made an arduous 70-day collecting trip through the Bonneville Basin of Utah and Idaho, which Hubbs later referred to as "a trip from Heaven to Hell" (Miller and Shor, 1997). However, despite this strenuous trip, Hubbs and his son-in-law Robert Rush Miller (1916–2003) later became the greatest authorities on the fish faunas of both basins, and of North American desert fishes in general.

During subsequent years, Snyder investigated the fishes of the tributaries of San Francisco and Tomales Bays on the central California coast; the coastal streams of northern California and Oregon; the Santa Ana and Mojave Rivers of southern California; Lake Tahoe; Owens River, east of the Sierra Nevada; and the San Pedro Mártir range of northern Baja California, describing several new species (Böhlke, 1953). Snyder developed a biogeographical way of looking at ichthyofaunas, which he passed on to Hubbs and George Sprague Myers (1905–1985), especially.

Publication Overview

As listed in Dean (1916, 1917), Snyder's publications from 1900 to 1909 were mostly as junior author to Jordan in an extensive series of reviews (about 35) of Japanese fish groups, mainly at the family level, although 6 of these were by Snyder alone, culminating in Jordan et al. (1913). These publications were based largely on *Albatross* collections. Snyder did most of the actual work on the specimens, since Jordan was developing an allergy to alcohol, later extending to Formalin, and had many other "irons in the fire" (Brittan, 1997). Snyder also published papers (a few with Jordan) on the fishes of Hawaii, Formosa (Taiwan), and Okinawa based on *Albatross* collections, but from 1908 on his papers were on California freshwater fishes, and in a few cases, those of Oregon, Washington, Idaho, Nevada, and Utah (Taft, 1944). Many of these publications include ecological and distributional information on fish species now listed by the U.S. Department of Interior as "Threatened" or "Endangered" (Minkley and Deacon, 1991; Behnke, 1992). Such information has been a great help to later resource managers attempting to save these species (Behnke, 1992).

Later Years

In 1914, Snyder was called to the Smithsonian Institution's U.S. National Museum in Washington, D.C., where he spent the year as "Expert Ichthyologist" to help catalog and to put his many *Albatross* fish collections in order (Rich, 1943). Although offered a permanent position there at the end of

his stay, Snyder declined and returned to Stanford to resume his teaching duties (Anonymous, 1943). However, he still remained a field assistant with the U.S. Bureau of Fisheries during the 1920's, ready to conduct any fisheries research in the American West that the Bureau felt needed to be handled by a competent scientist (Rich, 1943).

During 1917 through 1922, Snyder divided his time between teaching at Stanford (Taft, 1944), serving on the Palo Alto City Council (Rich, 1943), and being a member of the very important "Committee On Scientific Research Of The State Council Of Defense Of California" (Goodspeed, 1923). This group of distinguished scientists on the West Coast was originally part of the Pacific Division of the American of the Advancement of Science and had scheduled their annual meeting at Stanford on 5–7 April 1917.

However, with America's entry into World War I on 6 April 1917, their energies were immediately directed to the Committee mentioned above. This resulted in a number of important studies conducted on the potential of using noncommercial marine and freshwater fish, as well as other unutilized biological organisms for human consumption and for items directly related to increasing the domestic food supply for the war effort.

Snyder's role dealt largely with the Committee on Zoological Investigations where he conducted studies into the methods of preserving fish and other aquatic products. His initial studies were so promising, that they were subsequently transferred to the Nutrition Department of the University of California at Berkeley and to the U.S. Bureau of Chemistry (Goodspeed, 1923). One of the findings of this research resulted in the successful canning of tuna (Scombridae), which has subsequently become a commercially produced food product that is widely used today (at one time the 5th most common canned item present in the pantries of U.S. households).

From 1921 to 1931, Snyder investigated California Pacific salmon, *Oncorhynchus* spp., and steelhead trout, *O. mykiss*, fisheries, especially in the Trinity and Klamath Rivers (Snyder, 1931), and detailed life history, results of transplant and homing experiments, and statistics of declining catches. He attributed the latter to the harmful effects of gillnetting, too many small salmon entering the markets, and the inability of hatcheries to make up for overfishing (Taft, 1944). By this time, Snyder was becoming one of the premier salmonid authorities of his day, and his knowledge was much sought by students, fisheries management professionals, and legislators interested in keeping these economically important fisheries viable for future generations.

As a teacher, Snyder served as Assistant in Zoology (1897–99), Instructor in Zoology (1899–1903), Assistant Professor (1903–11), Associate Professor (1911–25), and Professor and Department Head (1925–31) at Stanford (Fig. 4). He also was an Instructor at Hopkins Marine Station in 1907 and 1908. While serving in these capacities, he steered several dozen students into ichthyology, fisheries biology, and conservation work, and oversaw 8 M.A. and 4 Ph.D. students; all without the benefit of the booming post World War II years, as did later zoology professors such as Myers and Willis Horton Rich (1885–1972) [and later, Donald Eugene "Curly" Wohlschlag (1918–2007)]. It should be noted that Stanford never had more than about 2,500 students before World War II, although the student body was of exceptional quality (Brittan, 1997). Known as "J. O." by his students and colleagues, all held Snyder in the highest esteem as a teacher, a scientist, and as a man (Anonymous, 1943; Rich, 1943).

After officially retiring at Stanford in 1931, Snyder was appointed as Chief of the Bureau of Fish Propagation for the California Division of Fish and Game (Taft, 1944). As part of his duties, he served as editor of the quarterly journal *California Fish and Game* and consistently guided this publication to timely releases and high quality content through the funding challenges of the Great Depression. Further, his articles on the trout, *Oncorhynchus* spp., *Salmo* spp., and *Salvelinus* spp., of California are still prized today by collectors for their useful information (Snyder, 1931), and their colorful illustrations (Snyder, 1933; 1940).

Snyder's leadership also resulted in a complete reorganization of the bureau along scientific lines (Rich, 1943; Taft, 1944). Because of his leadership position, a number of Stanford zoology students such as William Abbott Dill (1910–2000), Donald Hume Fry, Jr. (1905–76), Leo Shapovalov (1908–94), and Joseph Howe Wales (1907–2002), subsequently received their first professional job experience with the division. Indeed, upon his retirement, he left the administration of the bureau in the hands of a former graduate student [Alan Cowie Taft (1897–1975)] whom he had selected and trained especially for that work (Rich, 1943). Probably Snyder's most lasting legacy with the bureau (besides training and placing students), was the foresighted preservation of genetically pure stocks of native trout by planting them in isolated lakes of the Sierra Nevada so that they would be available for later generations to propagate and stock as management conditions warranted (Pister, 1990).

Personal Recollections

The senior author considers himself fortunate to have known well the ichthyologists Carl Leavitt Hubbs, Albert William Christian Theodore Herre (1869–1962), Rolf Ling Bolin (1901–1973), and George Sprague Myers, and the fisheries biologists Willis Horton Rich, William Abbott Dill, Donald Hume Fry, Jr., Leo Shapovalov, and Joseph Howe Wales, and, less well, Alan Cowie Taft, Frank Walter Weymouth (1884–1963), and Lionel Alfred "Bert" Walford (1906–1979), among others. All of these men were variously students, protégés, or colleagues of Snyder. Having sat in on many a "bull session" with my fellow Stanford M.A. and Ph.D. candidates—often at the Myers-Rich Stanford *Fischverein*, where many of these old-timers were attendees—they often talked about the "old days," and we graduate students were avid listeners to these gems of ichthyological and fisheries biology history. About John

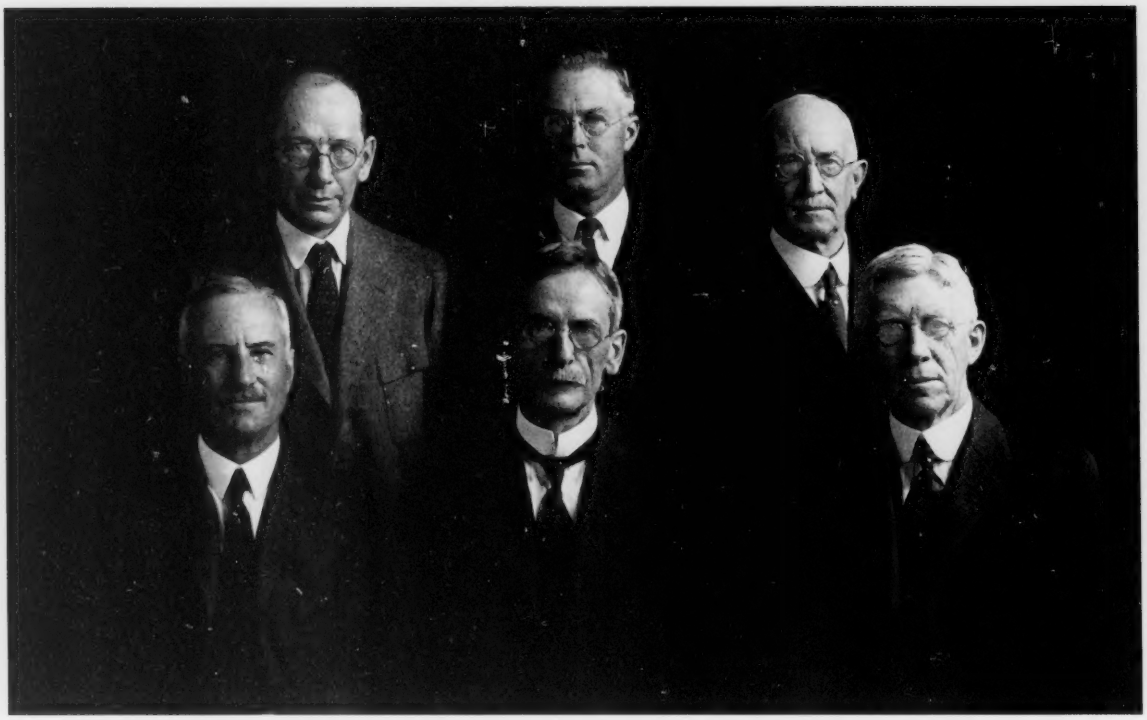

Figure 4.—John Otterbein Snyder and the Stanford University zoology teaching staff at Hopkins Marine Station in 1924. From left in lower row: John Otterbein Snyder, Harold Heath, and George Clinton Price; from left in upper row, Edwin Chapin Starks, Walter Kendrick Fisher, and Charles Henry Gilbert. Original photo courtesy of Stanford University Archives.

Otterbein Snyder, the words we heard most often, in addition to his scientific contributions, were "a stimulating teacher," "an excellent biologist," and "a fine man."

Lastly, Snyder was in the direct line of scientific descent from Baron Georges Leopold Cuvier (1769–1832), the most eminent naturalist of the Napoleonic and Bourbon periods of 18th-century France, considered the "Father of Comparative Vertebrate Anatomy," viz., Snyder, Gilbert, Jordan, Louis Agassiz (1807–1873), and Cuvier—a great heritage indeed.

Acknowledgments

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My Days on the *Albatross*

SEATON SCHROEDER

Prologue

Navigation and surveying formed a connecting link, as it were, between what was getting to be called the "Old Navy" and what was soon to take shape as a "New Navy." Seamanship, as an art of special character, was beginning to change its form with the passing of sail power and its supersession by the steam engine; while requiring in its new form no less ability and practiced judgment in the handling of large ships, it offered a diminished field for expertness in craft of only moderate size and speed among officers doing simple watch duty not in company with other ships; and, therefore, it was threatened with a materially lessened regard.

The third essential branch of the naval profession, ordnance, together with its employment under the name of Gunnery, was not even commanding serious attention, although a beginning was being made in the production of rifled guns, largely through the conversion of large caliber smoothbores into rifles of much smaller bore; also, the Fleet Ordnance Officer of the North Atlantic Squadron, Lieutenant J. F. Meigs, had come to be known as the Fleet Gunnery Officer and was attracting attention by his insistence upon the importance of target firing.

Conservative deliberation is commendable in the face of great changes; but many thought it was carried to the verge of paralysis in the process of advancing from cast-iron, through cast-iron and wrought iron, and wrought iron and steel, to finally all steel, with contemporaneous improvements in the mounts. It should be remembered, however, that we had an enormous amount of cast-iron ordnance on hand at the close of the Civil War; also, that the adoption of the rifle principle went naturally hand in hand with the advance in gun material, and everything waited upon the adoption of the rifle principle.

Hydrography

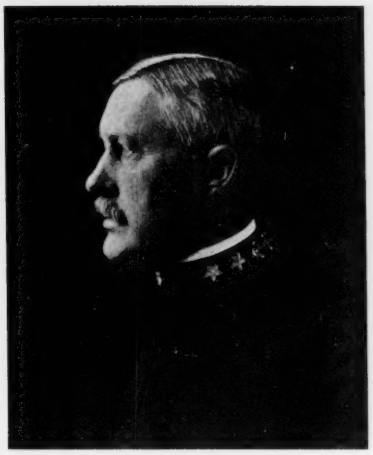
So, in the autumn of 1880, I (Fig. 1) looked forward with relish to duty in the U.S. Navy's Hydrographic Office, which anticipation was fully confirmed, and I passed two pleasant years there, interrupted only during 6 months, the winter of 1881–82, by special duty in surveying Samana Bay in the Dominican Republic. For that work the *Despatch*, Presidential yacht so-called, was detached from her usual sphere and fitted out as a surveying vessel, under the command of Commander William R. Bridgman who gladly accepted the duty, declaring that he would have considered it infra dig to command her in her normal service.

Commander Bridgman was a strict disciplinarian, a quality to which no one can rationally object; very uncompromising in his ideas regarding the performance of duty; reluctant to concede the superiority of steam over sail; a bon vivant and quite imbued with a desire to live and let live; quick to discern the qualities, good or bad, of those under his command, and not overly solicitous to conceal from them the impression made by discernment. One could not help liking him, or, certainly, admiring him.

The little ship of 600 tons was well equipped temporarily for her work, and

EDITOR'S NOTE—The year 2008 is a historic one in marine science. It marks not only the initial cruises of the world's first deep-sea oceanographic research vessel *Albatross* in 1883, but it also marks the centennial of the *Albatross*' cruise to the Philippines in 1908, an event being marked by Philippine authorities. Because many early accounts of the *Albatross*' work are long forgotten or very difficult to locate, we are reprinting a few significant ones, beginning with Rear Admiral Seaton Schroeder's account of his 3 years on the *Albatross* that was published as a chapter in his autobiography, *A Half Century of Naval Service*.

As with other accounts, Admiral Schroeder's chapter reflects the admiration and awe that most on the vessel experienced, owing partly to the vessel's advanced equipment (the latest research gear and, importantly, her use of electric lighting for some undersea work) and to the many thousands of new species brought on board. While late in the *Albatross*' career, some U.S. Navy officers thought poorly of duty on her, Schroeder was much impressed and was very appreciative of all he learned there. He was also much impressed with the capabilities and direction of the *Albatross*' captain, Lieutenant Commander Zera Luther Tanner, who seemingly took as much interest in her biological work as in his Naval work, helping invent or improve some of the research gear used. Thus began the 40-year career of the most productive marine science vessel of her era.



The vessel was put in commission when Captain Tanner reported for duty, and was supplied with the necessary officers and men by successive detail. The vessel left Wilmington on a trial trip for Washington on December 30, arriving on the 1st of January, 1883. The workings of the machinery were carefully studied, and the vessel taken back to Wilmington for final completion.

The *personnel* of the Albatross, on arrival at Washington, was as follows: Lieut. Z. L. Tanner, commanding; Lieut. Seaton Schroeder; Lieut. S. H. May; Lieut. A. C. Baker; Lieut. C. J. Boush; Ensign R. H. Miner; Paymaster George H. Read; Engineer G. W. Baird; Surgeon J. H. Kidder.

Figure 1.—Left: Rear Admiral Seaton Schroeder (1849–1922) was the first executive officer of the *Albatross*. Photo courtesy of the NOAA Central Library, Image ID pers0115. Above: Personnel first assigned to the *Albatross*. Image courtesy of the Rep. of the Comm. of Fish and Fish. for 1882, p. XXVII.

in her were crowded 16 officers, so that four parties could be kept at work independent of the care of the ship. I was the Navigator; and among the other line officers several had had excellent experience in that kind of work in the U.S. Coast and Geodetic Survey, which was a fortunate thing and contributed greatly to the excellence of the results. The essential factor, however, was the high standard of precision required by Captain Bridgman.

As an instance, I shall never forget taking in to him one day a working sheet, on a scale of 5 inches to a mile, to show him the hydrographic stations that we had established to angle on from the sounding boats. When I said something about those stations evidently being established with considerable accuracy, he assented somewhat reluctantly; but, after examining the sheet with a large magnifying glass, he pointed to one of them located by five "cuts" and commented that one of the cuts was only tangent to the pinpoint. It is no wonder that the chart-construction division of the Hydrographic Office declared it to be the best survey ever turned in.

The 5 months down there were passed in good hard work, the parties leaving the ship at half-past seven in the morning and getting back by perhaps half-past five, though not infrequently not until well after dark. Two of the four parties, of which I had one, did the shore work with theodolite sextant and micrometer telescope. The ship tried to keep conveniently near to where those parties had to go; but as the bay extends in to a depth of about 16 miles, the going and coming often amounted to a good many miles. We had steam launches for the hydrographic parties, while the triangulation parties had only pulling boats; but the crews of those boats became splendidly trained and would pull a racing stroke for miles. The return to the ship was generally under sail; in the afternoon the sea breeze rarely failed, and it was generally so fresh as to require reefing, and care was taken to have the ship always to leeward.

One day was had a rough time with my boat, which was a whaleboat equipped with the sliding-gunter rig. The sea breeze amounted to a young gale and we sped before it at a great rate, but when just about abreast the bow of the ship and preparing to brail up the foresail and bring by the wind, the boat broached-to and filled nearly up to the thwarts, and it took quick to earnest work to bale out that water and at the same time fetch the ship and not drift to leeward astern of her.

At another time we had a quite exciting race with a thunderstorm. My party had the south shore of the bay, and we were close-in on the roots of some tall mangroves and could see nothing except to the northward. Early in the afternoon we noticed that it was getting quite dark. The ship appeared in a peculiar light, being anchored about 2 miles off, and was flying a signal that looked like our boat's recall. It seemed so queer that I had the boat manned and we pulled away from the mangroves and found the whole southern board enveloped in an ink-black cloud which was advancing rapidly, while apparently torn with gusts and rent by flashes of lightning.

It was not necessary to give the order "Give way"; those seamen saw we had a race with that storm and gave way with a will. We had not gone a hundred yards, however, when the boat grounded on a bar. "Overboard everybody," and we "lighted her over," and started again. The same thing happened once again, after which we had a clear course, and the boat fairly flew. I could see that the boat falls were overhauled down on board the ship, and the crew were manning them; so I steered to bring the boat under the falls, and she was quickly hooked on but was barely clear of the water when that storm broke on us with rain and furious wind.

As an outing the work was thoroughly enjoyable—to those who enjoy that sort of thing, as I did. The only fly in the ointment, and a big fly it was, was that in the matter of eating we lived abominably. The member of the mess whom we had elected to the thankless office of caterer, as the mess treasurer was then

called, had not appreciated the isolated character of that bay and had made little provision for the table. There was but one steamer arriving there every 5 weeks, originally from New York, and it was not until the second one had come and gone that he seemed to awaken to the possibility of utilizing her.

The little village of Santa Barbara, near the mouth of the bay, had but scanty resources; once or twice did we get some tough fresh beef and some onions, and with regard to the latter I acquired a taste that I had never enjoyed before. There was no ice, of course, and no way of keeping fresh meat. As in the long passages in sailing ships, ice water was something that we remembered having read about; but we had no desire for it, as the monkeys (water bags) cooled the water quite as much as we liked.

For the picnic lunch taken in the boat, I always took a bottle of coffee, made the evening before and cooled during the night; by keeping it wrapped in a wet cloth and hung in the breeze, it was very palatable and refreshing. My friend Gorringe, of his own accord, sent me a big box of all sorts of things—preserves, cheese, potted things, slab chocolate, honey, sardines, cakes, puddings, etc., which made me very popular for a while in the mess. Chocolate and hard-tack, washed down with cool coffee, made a very satisfying luncheon; and I would, whenever possible, get into some shady nook with the boat and crew and get the greatest enjoyment out of it.

It so happened one day that my mental activities became engaged in a subject quite foreign to our work. I had the use of a steam launch for a special purpose in the mouth of a little freshwater stream that made its way out through a maze of mangroves, and I observed a peculiar wave action imparted to the water by the bow of the launch as it advanced. This led to an interested consideration of the matter which I afterwards embodied in a paper before the U.S. Naval Institute, entitled "A U-Bow Section and a long Buttock Line." The matter was, briefly, this: At a constantly moving point on either bank, if anything a little ahead of abreast of the bow, a wave hollow was formed, followed by a marked corresponding crest, the disturbance apparently ending after the passage of the crest. The hollow must have been preceded by a broad, unnoticeable elevation of the surface, which, under a reasoning given in detail in the paper, I attributed to the pressure of the particles of water being pushed downward, as well as laterally, by the bow of the advancing boat. This suggested a wall-sided bow, in other words, a U-Bow Section, as the shape encountering least resistance to forward motion because of pushing the water straight out laterally.

The element to which I afterward learned to attach the greater importance was the incontrovertible fact that the lower and greater part of the void under the afterbody, constantly being made by the forward motion of the ship, is filled from underneath. In order to counteract to the utmost the retarding effect of the diminished pressure under the run, it is necessary to give as free ingress as possible to the water flowing in as the vessel advances, and that manifestly can be the most naturally accomplished by so shaping the bottom that the water can begin to rise well forward, that is, by giving her a long buttock line, and that cannot be well done except in association with a bow section of a more or less U-shape. The way a vessel "squats" when running in shoal water is proof enough of the lack of pressure and buoying power under the stern, caused by the water not flowing in freely.

The long buttock line, expressed in other terms, is an old story perhaps; but it is strange what failures there were to recognize the various bearings of the phenomenon of the water coming from underneath to fill in under the stern. Anything that checks that inflow must retard the vessel, and among such checks obviously is shallow water under the bottom; and yet, 5 or 6 years after the time of my Naval Institute paper, one of the greatest shipbuilding firms in the country wasted some time and a great deal of money in trying to make a vessel that they were building come up to her contract speed in shoal water. When, finally, a course was laid off in deep water, that vessel made her speed easily and with less horsepower than was developed on the unsuccessful trials. It is interesting to recall that within a few years after that, when courses were laid in the deep water off Cape Ann, Mass., for the speed trials of large vessels, objection was made to one course in that in one place there was a small area where the depth was only 25 fathoms.

In all that special work of the *Despatch*, uniforms had to be discarded. We quickly learned to dress entirely in blue flannel, however hot it might threaten to be. Besides, we often had to be in the water for a while with no thought of a change until the ship was reached, and flannel was the only stuff with which to meet that condition. One hot day, while we were working in water about knee deep, erecting a station at the outer end of a mud flat, a hailstorm came up, and it was so cold that we had to lie down in the water to keep warm. It was noticeable that among those who had the bracing, out-of-door work and exposure there was no sickness, while those who had the ship duty, such as the Executive, engineers, the doctor, and the paymaster, several suffered from fever.

Our work included establishing the latitude and longitude as accurately as was possible with the instruments we had. Upon arrival, we first ran meridian distances several times, with our special outfit of chronometers, between Santa Barbara and San Juan, Puerto Rico. At that time I first made acquaintance with what we now call Porto Rico cigars; the acquaintance soon grew into intimacy.

As the spring passed and summer approached, other duty was being contemplated for the *Despatch*, and in May we were called north. It was becoming quite hot, and the rainy season was approaching, too, so that regrets at quitting that picnicking work were tempered. Upon reaching Washington, we were all detached.

To the *Albatross*

I returned to duty in the Hydrographic Office for the summer, being engaged in devising the plan and scope of Azimuth Tables and doing some of the computing. Before the computing was entirely completed, however, at the instance of

Lieutenant Zera Luther Tanner (Fig. 2) who was to be in command, I was invited by the Commissioner of Fish and Fisheries, Spencer Fullerton Baird (Fig. 3), to join the steamer *Albatross* (Fig. 4), then being completed, as Executive Officer and Navigator, an offer which I gladly accepted, and I was so ordered in October 1882. In any vessel in the regular Navy I would probably have had to worry through a period of watch duty in a commonplace, low-power steamer with a broadside battery of smoothbore guns on wooden Marsilly carriages, and with nothing to relieve the tedium of those wretched years, so I considered myself very fortunate to get this assignment.

The *Albatross* was a small vessel [234 feet long], not much over 1,000 tons, built of steel, with twin screws. She was the first government vessel to be equipped with an electric illuminating system. The environment, therefore, was of a distinctly progressive nature. The duties of the Executive were, of course, very light in so small a vessel; but as Navigator I had opportunity to gain more experience and skill in offshore navigation and inshore piloting than I would have had in many more years in a man of war, for we were always on the go, and on work requiring precision. I can never be too thankful for the practice of that cruise.

Before completing the 3 years and a little over, in that little ship, I realized that my greatest good fortune lay not so much in the mere experience gained in navigation as in the association with the Captain, Lieutenant Tanner. He had entered the Navy from the Volunteer service at the close of the Civil War. Being, unfortunately, more advanced in years than many about him, he reached the retirement age before attaining a rank higher than that of Commander.

Caught by the drastic reduction of the Navy in 1870, he long remained a Lieutenant, but was promoted to Lieutenant Commander shortly after our ship went in commission, and having been for some years on special duty with the U.S. Fish Commission vessels, naturally he was chosen for the command when the *Albatross* was built.

Figure 2.—Zera L. Tanner (1835–1906), the first commanding officer of the *Albatross*. Photo courtesy of the NOAA Central Library, Image ID theb3604.

Figure 3.—Spencer Fullerton Baird (1823–1887), first Commissioner of the U.S. Commission of Fish and Fisheries. Photo courtesy of the NOAA Central Library, Image ID pers0097.

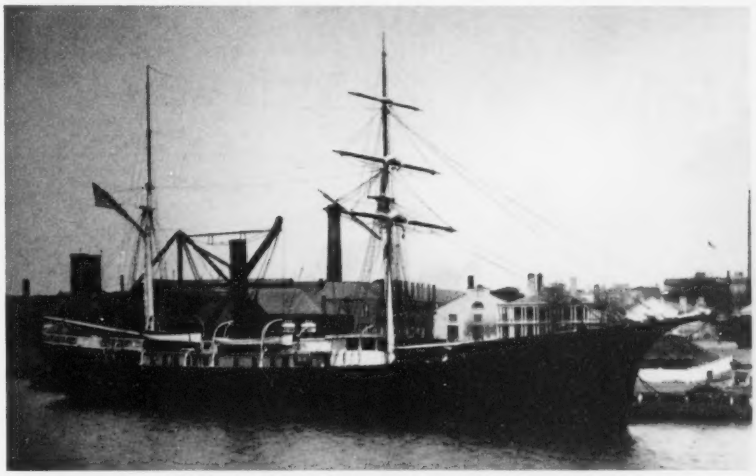
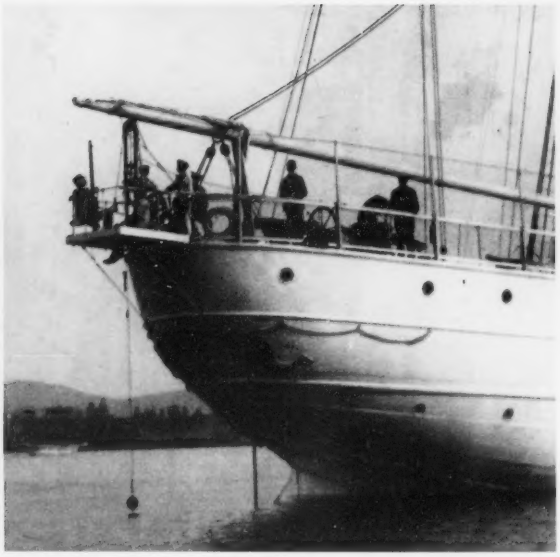
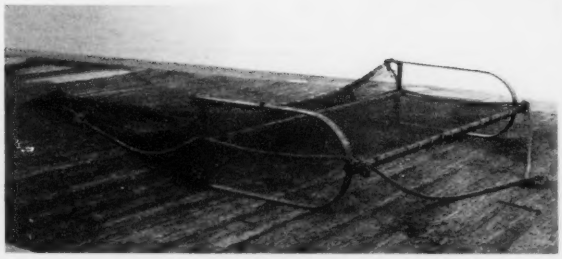


Figure 4.—The *Albatross* at the Washington Navy yard. Photo courtesy of the Natl. Archives, Image 7412.

He had commanded big ships in former times and was a consummate seaman; but apart from ability in the techniques of the profession, he had a remarkable insight and balanced judgment regarding both men and things, coupled with an iron nerve and decisiveness.

I have always felt that I owe more to his personality and unconscious example during those 3 years than to those of any other one man, and that is saying a great deal, for I have served with many, both senior and junior to me, from whom I have drawn inspiration as well as useful and practical suggestion. I also learned in that school how much more impressive and effective is unconscious example than studied example merely exemplifying precept.





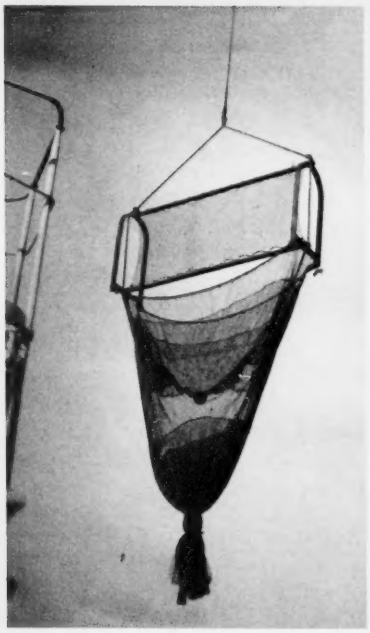


Figure 5.—Examples of gear onboard the *Albatross*. Top left: The stern, showing the Sigsbee deep sea sounding apparatus. Photo courtesy of the U.S. Army Military History Institute. Bottom left: Crew sampling with surface nets. Photo courtesy of the National Archives, Image 7184. Top and bottom right: Blake deep sea trawl. Photos courtesy of the National Archives, Image 7431 (top) and Image 7420 (bottom).

Our little ship was designed and thoroughly equipped for the exploration of the deep sea, having the latest sounding and trawling and dredging machines with all their perfected accessories (Fig. 5). The exploration consisted of more than ascertaining depths, temperatures, specific gravities, and obtaining cup specimens of the bottom; there was much that was of major interest to biologists and students of natural history, for with our trawl nets we would bring up specimens of life on the bottom at depths of 2,000 fathoms and at intermediate depths, and, with the dredges, large samples of the bottom with the fish found there. Soundings and temperatures were also obtained from a depth of 4,000 fathoms.

The operations were not solely in the interest of science. There was one subject of perhaps more immediate popular concern than the "specimens," and which was said to have had its due

weight in determining the building of the ship. In 1879 a New England deep-sea fisherman, driven somewhat off the usual Atlantic cod, *Gadus morhua*, and hake, *Urophycis* spp., fishing ground south of Nantucket, caught a lot of fish of entirely novel aspect which proved to be an exceptionally fine food fish. They would average perhaps 10–20 pounds in weight, with flesh not unlike that of the cod, and with a pleasant flavor; it was also a more economical fish than the cod, a greater proportion of the weight being edible.

One of the fish was sent to the Smithsonian Institution's National Museum where it was duly described as a new species and named *Lopholatilus chamaeleonticeps*; the common name given was tilefish (Fig. 6). Its feeding ground becoming defined, it was caught in increasing numbers each year until the spring of 1882, when incoming ships reported having passed through immense fields of dead fish while crossing the northern edge of the Gulf Stream. Investigation proved them to be tilefish exclusively, and it was estimated that about one billion, five hundred million had been killed by some environmental change, the nature of which seemed to defy conjecture.[1]

Professor Baird, the eminent Commissioner of Fish and Fisheries, had recognized the importance of developing tilefish fisheries when those fish gave promise of abundance. He was equally keen to discover if the family had been completely exterminated or if a few individuals had survived and would reproduce, and the *Albatross* was looked upon as a useful agent in determining that question and also in obtaining light upon the history of the fish. We, therefore, made careful surveys and studies of the waters that they had frequented, making temperature and specific gravity observations, and in different years we made many casts of the trawl net and of the dredge not only to bring up tilefish if possible, but to procure samples of the bottom where they would feed and to examine the contents of the stomachs of such other fish as were brought up, to determine if the food they contained was of a kind that tilefish would eat.

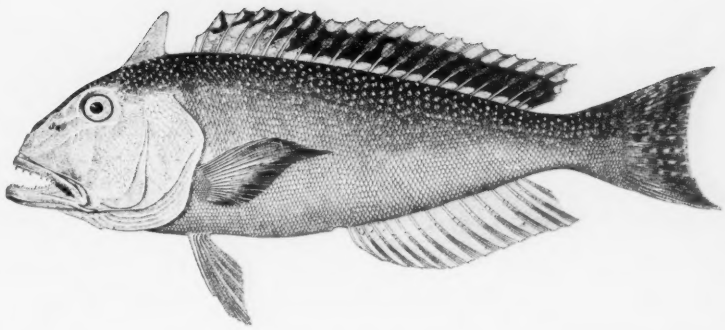


Figure 6.—The tilefish. Image courtesy of the NOAA Central Library, Image ID fig0378.

At every haul in those waters there was eager examination of the net in the hope of seeing the distinctive, large, round, yellow spots; but none were obtained. The other and smaller vessels of the Commission prosecuted the search at the same time with immense trawl lines carrying sometimes 1,000 hooks. But that search also was unavailing.

The search was unavailing only in the failure immediately to obtain an individual fish. The research, under the enlightened methods of the Commission, later [1903] known as the Bureau of Fisheries, solved the mystery of the sudden, apparent creation of the new fish, and determined the cause of its all but total extinction, and forestalled surprise at its reappearance in 1892. Its sudden appearance, in 1879, was simply its discovery; it had presumably existed there from time immemorial.

In brief, the explanation is this: the structure of the tilefish permits and requires it to live under the pressure found in deep water as a bottom fish; at the same time, examination of its habitat shows it to be a denizen of rather warm water; these two conditions coexist only on and near the edge of the continental shelf paralleling, in general, the southern coast of New England and the Jersey Coast. At depths of from 60 to 150 fathoms is found the inner edge of the warm water of the Gulf Stream, inshore of which runs the cold Arctic countercurrent; and that belt is where the tilefish was found.

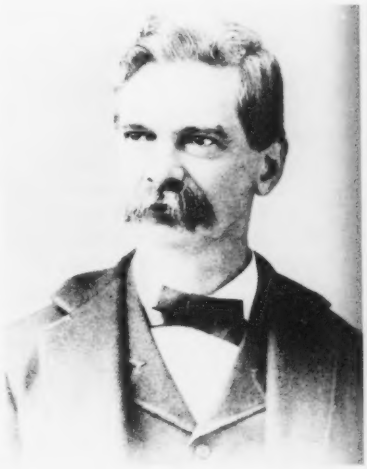


Figure 7.—Prof. A. E. Verrill (1839–1926). Photo courtesy of the NOAA Central Library, Image ID pers0099.

Its destruction was quickly explained by Professor Addison E. Verrill (Fig. 7) as due probably to a forcing outward of the cold water, as a result of a severe storm which occurred at that time, thus causing throughout that narrow zone a sudden lowering of the temperature which could not fail to be fatal to the warmwater fish. A remarkable coin-

[1]For additional information see Collins, Capt. J. W. 1882. History of the Tile-fish. *In* U.S. Comm. Fish Fish., Rep. Comm. for 1882, App. B., Sect. XI, p. 237–292.

cidence, seemingly providential in its character, is that the crustacean upon which the tilefish feed are limited to much the same physical conditions as the fish that feed upon them; there was noted a marked absence of them too in the same localities and depths where, previous to the cataclysm, they had been found in vast numbers. By 1898 the tilefish was entirely reestablished in its old habitat.

Another study considered by the Fish Commission, in which it was thought the *Albatross* could help, was that of the migrations of the shad, *Alosa sapidissima*, on the Atlantic coast (Fig. 8). Each spring that dainty fish appears, first in Florida waters and successively in freshwater rivers farther north, but, after accomplishing its task of depositing its spawn and incidentally giving joy to epicures during the summer, it disappears, and its farther movements are unknown.

We could not discover anything of value. It does not come to the southern coast in one huge school and wend its way northward; its appearance off Charleston, S.C., in the Chesapeake Bay, the Delaware River, and the Hudson River, off Boston, and in the Bay of Fundy are so close as to indicate a progress faster than it can swim; evidently different schools approach each freshwater outlet independently from the direction of the Gulf Stream. The suggestion that it returns to deep water, diving under the Gulf Stream, is met by the sole and somewhat negative argument that it has never been seen outside of that stream.

While working in that interesting zone southward of Martha's Vineyard and Nantucket, we occasionally made hauls, in the trawl nets, of one kind of fish that interested us peculiarly. That was the witch flounder (*Glyptocephalus cynoglossus*) (Fig. 9), the peculiarities of which were that it had a delicious flavor, much like the sole (Soleidae), and was possessed of a mouth too small to take a hook large enough to land it. The latter feature was prohibitive of taking them for commercial purposes; but I understand that there has been an enterprise on food to take them for the

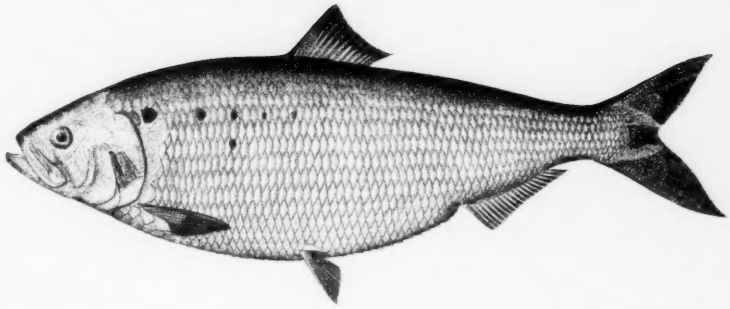


Figure 8.—The shad. Image courtesy of the NOAA Central Library, Image ID fig0480.

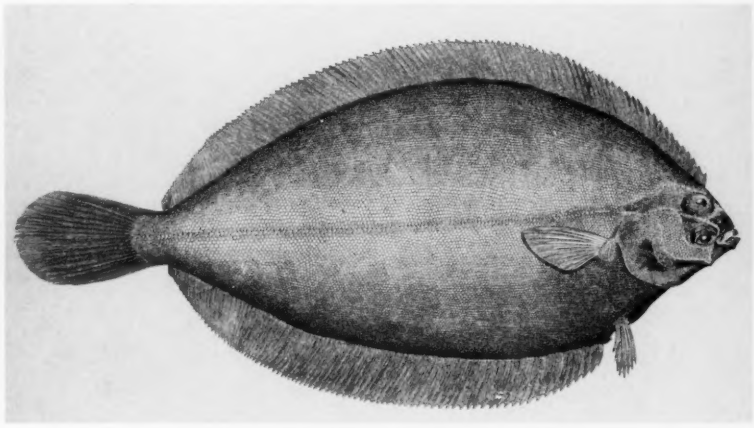


Figure 9. —The witch flounder (formerly pole flounder). Image courtesy of the NOAA Central Library, Image ID fig0313.

New York market. In that region also we often had a nice luncheon of sea scallops, *Plactopecten magellanicus*, brought up in the dredge.

The Fish Commission's headquarters for the summer was at Wood's Hole, Mass., (Fig. 10) we would be out on the ground as long as the coal lasted, and then go in there for coal and to clean up and have a day or two of relaxation. So the summertime passed most pleasantly.

Chart Improvements

Our work, however, was not limited to the region of No Man's Land. It extended from Trinidad to St. John's Newfoundland, and all about the West Indies and the Gulf of Mexico, being north in summer and south in winter. Incidentally we expunged from the charts a great number of "Reported Dangers," contributing to the ease of mind of many mariners. The depths that we found in those reported positions in the Atlantic were about 3,000 fathoms (18,000 feet) so often as to cause joking comment; in the Caribbean Sea they were less. We had an opportunity to see how seriously impressed ship captains could be with those pseudo shoals.

At Curaçao we met an American tramp steamer whose captain came on board to ask if we had located a

shoal reported in a certain latitude and longitude and which he had recently verified. He described how he had seen the gulls flying excitedly about and had gone close enough to see the surf clearly breaking over the reef but had finally sheered off and given the place a wide berth. I remembered our search well, as we had just finished it. Seeing the birds circling about, and then what seemed to be surf, we had approached cautiously with the hand lead going until right in the middle of the disturbance when we tried with the deep-sea sounder and reached bottom at something over 2,000 fathoms. It was a tide rip which probably formed in that general vicinity regularly at certain stages of the tide, and the birds were attracted by the flotsam.

We did not encounter very much bad weather; but we had enough to show us that that little vessel was a remarkable sea boat. Her weights had been so skillfully distributed that lying-to in a heavy sea she would rise and fall with scarcely any roll. In one gale we tried a method of lying-to that had been practiced by one of the White Star liners, which consisted of hoisting the forestorm staysail and stopping the engines; she lay there with the wind and sea a couple of points abaft the beam, as comfortable as an old shoe.

One winter we were were loaned to the Navy Department and, for the Hydrographic Office, sounded out the Caribbean Sea, running lines of soundings across it. While sounding, which would sometimes take an hour, valuable data were also obtained about the currents; using the engines to keep the wire vertical, so as to have "an up-and-down cast," both the strength and the direction of the current could be noted.

It was interesting; at the same time it was quite strenuous work for the Navigator. I would be in the chart house; the officer of the deck would call me when about to stop and take a sounding; while he was handling the ship for the sounding, I would take observations of the two stars (if at night) at approximately right angles to each other, work out and plot the position, give the course and distance to the next sounding, about 12 miles off, lie down and be asleep in no time and up and ready for the next one; and that would keep up as long as the coal lasted. We visited many small, out-of-the-way places, which have always held a certain fascination. Among other ports we passed a week or so at Kingston, Jamaica, and I found several old friends there who had not forgotten our tour to the West Indies aboard the U.S.S. *Canandaigua*.

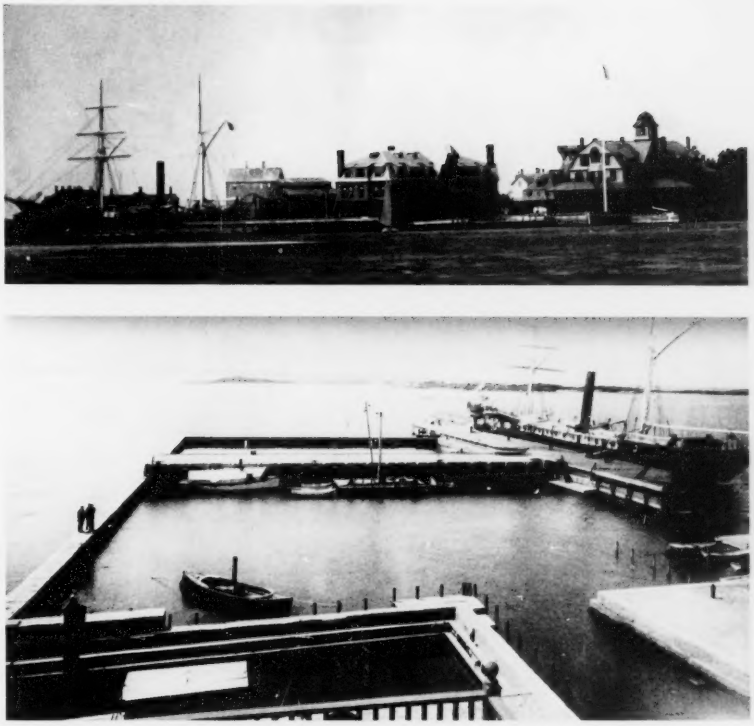


Figure 10.—Woods Hole, Mass. Top: Looking northeast with the *Albatross* at the wharf. Photo courtesy of the NOAA Central Library, Image ID fish7226. Bottom: Woods Hole wharves with the *Albatross* at right. Photo courtesy of the NMFS Northeast Fish. Sci. Center, Image hisa-015.

Gulf Research

The Gulf of Mexico was a fruitful field for research in the way of fish. We got in touch with the fishermen of those waters, and we soon learned the food value as well as the pleasant flavor of the pompanos, *Trachinotus* spp., red snappers, *Lutjanus campechanus*, and certain other species. We found also that those fishermen were becoming depressed over the outlook with regard to the snappers, as the banks where they were found were becoming "fished out"; some of the men were even talking of finding other employment for their boats.

By great good luck we were able to lend them an unexpected helping hand. While trawling and dredging in comparatively shallow water, 25–35 fathoms, not far off the west coast of Florida, we brought up some bottom fauna that the naturalists of the Commission quickly recognized as food on the snappers; so we threw over some lines, with two hooks on each, and instantly pulled them up with a fish on each hook. It did not take long to spread the news; and we found densely populated ground of a considerable extent that was a godsend to those fishermen.

While in the Gulf in the winter of 1884–85, we went up the Mississippi to New Orleans at the time of the World's

Figure 11.—Hon. William E. Chandler (1835–1917). Photo courtesy of the Library of Congress, Prints and Photographs Div., Digital ID cwpbh 03803.

Industrial Fair and, being moored at the end of the pier, were open to visitors all day, during a week, as part of the Exposition. A large number of people flocked on board, and many seemed quite interested in our apparatus.

One thing in the Exposition that attracted much attention was the incandescent electric lighting of an auditorium where concerts were given. That mode of lighting was still in its infancy, and the point of switching on suddenly a large circuit had not been reached; with the circuit closed, the dynamo had to be sped up gradually, the lights beginning with a faint glow which quickly attained to the proper brilliancy amid the applause of the audience. Electric lighting for general use had not yet been introduced in the city, and that useful display was probably made partly as an exhibit.

The officers of the *Albatross* were interested especially in the tangible results that flowed from a large part of the operations. The dredgings often produced material that was important principally as a subject for detached scientific study and which would appeal more strongly to the naturalists than to the officers, but the latter would still have the responsibility of handling the ship and apparatus to secure the results.

For me, personally, the interest in the navigation and piloting was generally paramount; at times there would be situations that quite relieved any monotony that might exist in that branch of the work. One such occasion arose in August 1884. We were at Newport, R.I., and the Secretary of the Navy, William E. Chandler (Fig. 11), came on board by invitation of the Fish Commissioner to take passage in the ship to Wood's Hole.

We proceeded to sea, taking our departure from Brenton's Reef lightship, and almost immediately ran into the dense fog. We kept on, headed for the Sow and Pigs lightship off the western entrance to Martha's Vineyard Sound, about seventeen miles from Brenton's Reef. In due course we heard her fog signal right ahead, which verified our compass course; but before long we suddenly ceased hearing it and were greatly perplexed. When we had run the distance I so informed the captain and advised against standing on without some check for the position, for the course changed there for entering the Sound.

The captain had hardly rung to stop before a tremendous blast sounded right alongside and we made out the outline of the lightship not 50 yards away. We investigated the matter afterwards, and learned that there had been no interruption of the whistle at that time. It was simply a noteworthy instance of the aberration of sound, which under certain conditions of varied temperature causes its horizontal carriage to be broken by zones of silence when the vibrations are refracted upward over large areas but may return to the surface farther away.

That, of itself, was an interesting incident; but what was uppermost in our minds at that time was the problem of entering Martha's Vineyard Sound and finding Wood's Hole in a dense fog which would soon be reinforced by the shades of dusk. Captain Tanner said that it would never do to let the Secretary of Navy think that a naval vessel could not go through a fog. Shortly afterwards he added, "I'll hold her here by the lightship. You go and work out the tides and currents, and courses and distances, and we'll stand on." So I went into the chart house and studied the probable strengths of the currents which run from 1 1/2 to 2 and a half knots an hour, eastward at one time of the tide and westward at another, and are deflected partially into or out of Buzzard's Bay.

From this study I made out a little table of courses to be run, with the number of miles and tenths to be made on each, to carry us into and up the Sound clear of Lucas Shoal and the Middle Ground on the starboard hand and of the Elizabeth Islands on the port hand; fortunately the shores of the latter are quite bold and steep-to. It was about 18 miles from there to Wood's Hole. As soon as I returned to the bridge we started ahead, having cautioned the engine room that it was important to maintain a uniform rate of speed, and having the comfortable assurance that that could be relied upon. It was very blind running; but we made the courses and distances carefully and were prepared for any eventuality. As we approached the completion of the run, I said to the captain that I thought we probably had not reached abreast of Wood's Hole, but pointed out that there would be danger in overrunning because of the foul ground off Falmouth beyond, and suggested that we stop the engines and put the helm a-starboard and we might then see or hear something.

This was done. Fortunately, it was deathly still. The officer of the deck had taken station on the forecastle, and I hailed him and asked if he could see anything. He replied: "No, sir, but I hear a cock crowing right ahead." That showed we were on the safe side of the channel, and we remained there for a while with the hand lead over; but after some minutes a light struggled through a rift in the fog close by, and remained in sight long enough for us to get a bearing and to recognize it as Tarpaulin Cove light, 4 miles from Wood's Hole. Knowing Tarpaulin Cove to have a clean bottom, we made for it and anchored, and at four the next morning, the fog having lifted, we ran into Wood's Hole; and the Secretary of the Navy was not delayed at all events.

Like all pleasant cruises, that of the *Albatross* had to come to an end some time. In January 1885, when the ship was preparing for the winter's work in southern waters, all of us who had been on board from the date of commissioning, except Captain Tanner, were detached. It had been an exceptionally pleasant cruise. A safe rule to accept is that a busy ship is a happy one; and the *Albatross* was not exception. Moreover, besides being busy, we were a congenial mess and did not get tired of each other, as might well have been the case with so much of the time passed in the isolation of the sea. We separated with cordial feelings all around.

Editorial Guidelines for the *Marine Fisheries Review*

The *Marine Fisheries Review* publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to the *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under a completed NOAA Form 25-700.

Manuscripts must be typed double-spaced throughout and submitted with two duplicate copies. The complete manuscript normally includes a title page, a short abstract, text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, headings, subheadings, and the abstract short and clear. Because abstracts are circulated by abstracting agencies, it is important that they represent the research clearly and concisely. Headings within each section must be short, reflect a logical sequence, and follow the rules of multiple subdivision (i.e. there can be no subdivision without at least two items).

Style

The entire text should be intelligible to interdisciplinary readers; therefore, all acronyms, abbreviations, and technical terms should be spelled out the first time they are mentioned. The scientific names of species must be written out the first time they are mentioned; subsequent mention of scientific names may be abbreviated. Follow the U.S. Government Printing Office Style Manual (1984 ed.) and the CBE Style Manual (5th ed.) for editorial style, and the most current issue of the American Fisheries Society's Common and Scientific Names of Fishes from the United States and Canada for fish nomenclature. Only journal titles, scientific names (genera and species), and vessel names should be italicized. Dates should be written as follows: 11 Nov. 1991. Measurements should be expressed in metric units, e.g. metric tons as t; other equivalent units may also be listed in parenthesis. Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. The numeral one (1) should be typed as a one, not as a lowercase el (l). Write out the numbers zero through nine unless they form part of measurement units (e.g. nine fish but 9 mm).

Footnotes

Footnotes should not be embedded within the text document. They must be numbered with Arabic numerals and typed on a separate sheet of paper. Footnote all personal communications, listing the name, affiliation, and address of the communicator and date of communication. Unpublished data and unpublished manuscripts should include the title, author, pagination of the manuscript or report, and the address where it is on file. Authors are advised to avoid references to nonstandard (gray) literature, such as internal, project, processed, or administrative reports, wherever possible. Where these references are used, please include whether they are available from NTIS (National Technical Information Service) or from some other public depository.

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Tables

Tables should be printed separately and double-spaced. Tables should not be excessive in size and must be cited in numerical order in the text. Headings should be short but sufficent to allow the table to be intelligible on its own. All unusual symbols must be explained in the table heading. Other incidental comments may be footnoted with Arabic numerals. Because tables are typeset, they need only be submitted typed and formatted, with double-spaced legends. Zeros should precede all decimal points for values less than one. Table headings and format should be consistent; do not use vertical rules.

Figures

Figures include line illustrations and photographs (or slides) and must be cited in numerical order in the text. Figures are to be labeled with author's name and number of figure. Use Times Roman font (upper and lowercase letters) to label within figures. Avoid vertical lettering except for y-axis labels. Zeros should precede all decimal points for values less than one. Figures should be submitted as both laser-printed copies and computer software files. Figure legends should explain all symbols and abbreviations and should be double-spaced on a separate page at the end of the manuscript. Consider column and page sizes when designing figures. Please note that we do not print graphics in color.

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